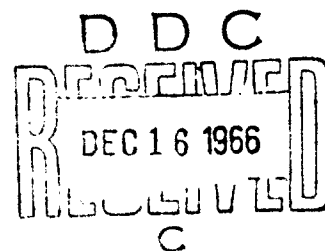
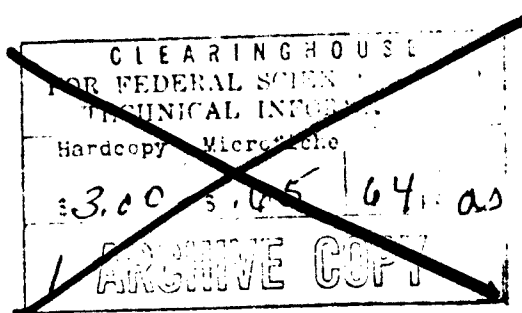


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COST ANALYSIS FOR PLANNING-PROGRAMMING-BUDGETING
COST-BENEFIT STUDIES

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November 1966



P-3479

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I. INTRODUCTION

The current interest in developing a Planning, Programming, Budgeting System (PPBS) in non-defense agencies stems to a large degree from its success in the Department of Defense (DOD). It is natural, therefore, for the non-defense agencies to look at DOD experience for ideas. For example, in the area of cost-benefit studies, an integral part of PPBS, the DOD has had long experience. It was on this basis, I understand, that I, a military systems cost analyst, was asked to discuss principles and techniques of cost analysis in support of cost-benefit studies. I understand that others in the course of this seminar have already introduced you to the subject of cost-benefit analysis.

Although the basic analytic principles are the same for studies conducted both for DOD and for non-defense agencies, the DOD area is loaded with jargon and I find it difficult to use DOD case studies to illustrate my points. I have developed a simplified, hypothetical cost-benefit example that involves the field of education to illustrate the key features of cost analysis. I trust that any HEW personnel in the audience will make helpful comments to improve any shortcomings in my examples.

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This paper was prepared for presentation at a series of three-week seminars on "Planning, Programming, and Budgeting" which are being conducted by the Office of Career Development, U.S. Civil Service Commission, in cooperation with the University of Maryland. Attendees are civil service employees who will be involved in the implementation and operation of the Planning, Programming, and Budgeting System (PPBS) in non-defense agencies.

**Cost-benefit analysis is also referred to as cost-utility analysis, cost-effectiveness analysis, or systems analysis.

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I assume that most of you will be consumers of cost estimates; however, some of you, especially in the smaller agencies, may be cast as generators of cost estimates as well. While my talk today is addressed primarily to the consumers of cost estimates, this discussion can perhaps serve as a starting point for those of you who may be newly designated as cost analysts.

The general sequence of my remarks will be, first, a review of the role of cost-benefit studies as a planning tool and the role of cost analysis therein; then a review of the principles and techniques of costing individual systems; and, finally, the costing of groups of systems.

II. THE ROLE OF COST-BENEFIT ANALYSIS^{*}

Let me quickly review the role of cost-benefit analysis. This will serve to insure that we are on common ground. I realize that you have already had some exposure during this seminar to cost-utility analysis, so I will be very brief.

To begin with, cost-benefit analysis is a tool employed in the analytical process considerations of Program Budgeting, as opposed to the structural aspects or the information system considerations.

The structural aspects of program budgeting are concerned with establishing a set of categories oriented primarily toward the "end-product" activities that are meaningful from a long-range-planning point of view.

Information system considerations deal with (1) progress reporting and control and (2) providing data and information to serve as a basis for the analytical process.

Analytical process considerations pertain to various study activities conducted as an integral part of the program-budgeting process.

The analytical process in PPBS covers the entire spectrum from long-range planning, to programming, to budgeting, and the analytical techniques employed vary with each part of the spectrum. I want to focus on one analytical technique, that of cost-benefit analysis.

Cost-benefit analysis, although not restricted in its application to long-range planning problems, is a most useful tool for such planning, particularly when a wide range of alternative future courses of action needs to be examined in a broad context.

^{*}For an extensive discussion, see Novick [1], Chap. 3.

Prest and Turvey define cost-benefit analysis as "a practical way of assessing the desirability of projects, where it is important to take a long view (in the sense of looking at repercussions in the further, as well as the nearer, future) and a wide view (in the sense of allowing for side-effects of many kinds of many persons, industries, regions, etc.), i.e., it implies the enumeration and evaluation of all the relevant costs and benefits."^{*}

To recap, cost-benefit analysis is a tool for long-range planning. I will thus be discussing cost analysis as a part of this tool for long-range planning. I will not be talking about techniques for preparation of estimates for, say, the funding of next year's budget, or for managing systems once the decision to develop or produce has been made. Cost analysis for these purposes takes a much different form.

III. THE ROLE OF COST IN COST-BENEFIT ANALYSIS

Before proceeding to discuss the principles and techniques of cost analysis in support of cost-benefit studies, I would like to mention the role of cost in these studies. First, I wish to review with you the tests for preferredness in cost-benefit studies, for it is in these tests that costs and benefits are related.

Cost-benefit analysis helps us in choosing the most desirable among the alternative means to our ends. To make a meaningful choice requires that we have criteria or tests for preferredness. The generally suitable form of criterion is the maximization of the present value of all benefits less that of all costs if both can be expressed in the same unit.^{**} If they cannot be so expressed, then the suitable forms are

^{*}Prest and Turvey [2], p. 683.

^{**}Money invested at some rate of interest will increase in value over time. For example, \$100 invested today at 6% interest will amount to \$106 one year from now. Looking at it in another way, \$106 one year in the future is worth only \$100 at present, if money is worth 6%. The sum \$100 is called the present value of \$106, one year in the future if money is worth 6%. The \$106 is discounted at 6% to determine the present value.

maximization of gain for a specified cost or the minimization of cost for achieving a specified gain.*

Let me illustrate these criteria by a hypothetical case study. This basic case will be used repeatedly throughout the paper; therefore, I will present it in some detail for the first illustration.

Assume that in an east coast metropolitan area there are 30,000 high school dropouts per year. The federal government has established an objective to train part or all of them by means of a one-year intensive training course which will make them employable at a certain skill level 10 years earlier than if they had to attain this skill level on their own. The benefits thus run for 10 years. To provide the training, assume that we must build entirely new schools, hire all new teachers, etc., and that the program itself will last 10 years. There are two alternative means to achieve the objective. Consider that each of these means constitutes a "system." A system, therefore, would be viewed as a combination of resources brought together to achieve a specific objective. System A is an equipment-oriented approach involving extensive use of computers, programmed learning techniques, etc. It has only 50 teachers per school and a student-teacher ratio of 60:1. System B is a teacher-oriented approach involving team-teaching techniques. It has 200 teachers per school and a 10:1 student-teacher ratio. The student capacity at schools for System A is 3000 and for System B, 2000.

Assume further that the costs (which I will define in detail in later sections) for each system are summarized below (in millions).

	<u>System A</u>	<u>System B</u>
Development -----	\$150.0	\$10.0
Investment per school ----	5.0	4.0
Operations per year per school -----	1.5	3.0

We are now ready to examine how costs and benefits are related in the tests for preferredness. First, let us assume that the benefits

* McKean [3], p. 97.

and the costs cannot be measured in the same unit, that is, they are incommensurable. In our case, gains are measured in numbers of students trained and costs are measured in dollars. Because our decisionmakers do not know the level of training they wish to support, we must develop a schedule of costs and benefits over the full range of students (0-30,000). For convenience, let us assume that the costs are continuous in nature; that is, we can buy schools of varying sizes.

The student load capability is charted on the top part of Fig. 1. System A requires 10 schools for 30,000 students and B requires 15.

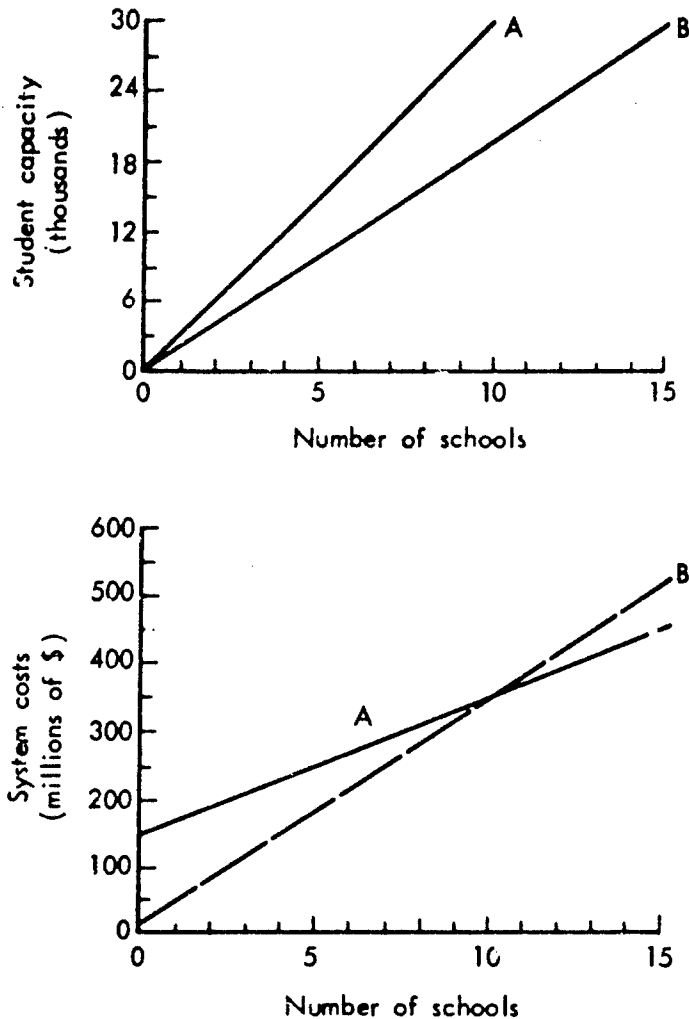


Fig. 1—Student capacity and system costs versus number of schools for alternative systems A and B

The system costs (Development, Investment and 10 years of Operating Cost) are charted on the bottom part of Fig. 1, and are summarized below:

COSTS
(In millions of dollars)

System A					System B			
Schools	R&D	Inv	Ops	Total	R&D	Inv	Ops	Total
0	150	-	-	150	10	-	-	10
10	150	50	150	350	10	40	300	350
15	150	75	225	450	10	60	450	520

We can now combine benefit (student capacity--assumed to be equal to students trained) and costs into one chart (Fig. 2) by eliminating the common denominator, number of schools.

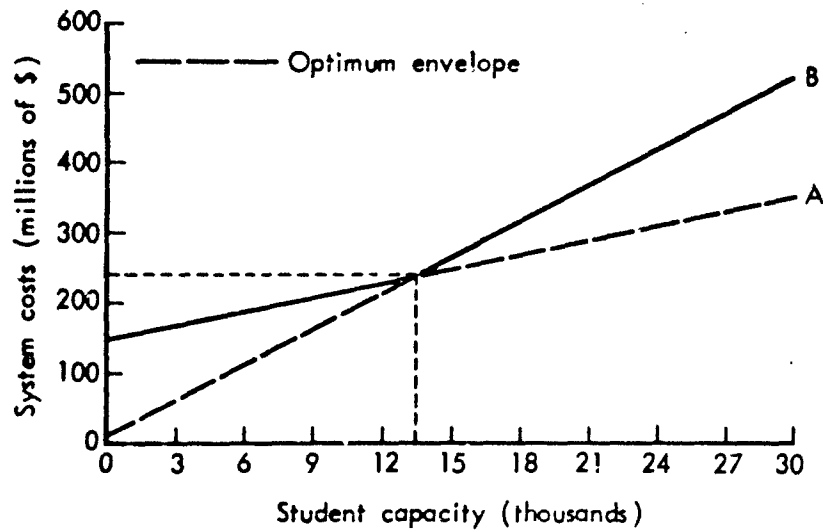


Fig.2—Student capacity versus system costs for alternative systems A and B

Recognizing that non-quantifiable factors will enter into the decision, but whose discussion will be omitted here for simplicity, we can choose the best system given either a fixed budget or a specified level of benefit. I have indicated the envelope of optimum costs to benefits. For all budgets under \$242 million, System B is preferred because it will have a greater student capacity. For example, at a \$200 million budget, System B has a capacity of about 11,000 students, while A has about 8,000. For all levels greater than \$242 million, System A is preferred.

Conversely, for all student loads less than 13,600, System B is preferred because it will cost less than System A. Above 13,600, System A is preferred. For example, at a 24,000 student load, System A will cost \$310 million whereas System B will cost \$418 million.

Although the above illustrations have been extremely simplified, they show how cost and benefits interact when they are incommensurable.

Again using the same basic case, assume that each student trained will increase his earnings such that, for the 10-year period, taxes paid to the government will be increased by \$250 each year and that unemployment benefits of \$250 per year will not have to be paid. The government, therefore, has the opportunity to use this \$250 in some other way. The net gain to the government is therefore \$500 per student per year or \$5000 for the 10-year period.

Recall that our criterion for choice is, for a given investment, the maximization of present worth, i.e., the present value of the benefits less that of the costs. We must now compute the time-phased benefits and, using an appropriate interest rate, discount the benefits to a present value. Again, the system costs would be developed as before, but in this case, they would be time-phased and discounted to a present value. Such time-phased costs and benefits for one level of student capacity are portrayed on Table 1, together with the present value of each, based on the arbitrary assumption that money is worth 6%.*

*The discount rate selected above is meant to reflect only the time preference for money and not the risk associated with the project. See Hitch [7], pp. 209-210. See also McKean [3], Chap. 5, for an extensive discussion of time streams and criteria.

Table 1

PRESENT WORTH CALCULATION - 6 PERCENT DISCOUNT RATE
ALTERNATIVE SYSTEM A - 30,000 STUDENT CAPACITY

(In millions of dollars)

Year	Schools in Operation	Costs					Benefits		Present Worth
		Dev.	Invest.	Op.	Total	Present Value	Total	Present Value	
1	--	75.			75.	70.8	--	--	
2	--	75.			75.	66.8	--	--	
3	--		50.		50.	42.0	--	--	
4	10			15.	15.	11.9	--		
5	10			15.	15.	11.2	15.	11.2	
6	10			15.	15.	10.6	30.	21.1	
7	10			15.	15.	10.0	45.	29.9	
8	10			15.	15.	9.4	60.	37.6	
9	10			15.	15.	8.9	75.	44.4	
10	10			15.	15.	8.4	90.	50.2	
11	10			15.	15.	7.9	105.	55.3	
12	10			15.	15.	7.5	120.	59.6	
13	10			15.	15.	7.1	135.	63.6	
14	--						150.	66.6	
15							135.	56.3	
16							120.	47.2	
17							105.	39.0	
18							90.	31.5	
19							75.	24.8	
20							60.	18.7	
21							45.	13.2	
22							30.	8.5	
23							15.	3.9	
Total		150.	50.	150.	350.	272.5	1500.	682.4	409.9

I have allowed two years for the period of development and test and one year to build the schools and install equipment. The schools operate for 10 years, graduating a total of 30,000 students each year. The graduate students build up in 30,000 increments to a maximum of 300,000 graduates receiving benefits. This group phases down by 30,000 decrements as the assumed benefit period of 10 years ends for each class. The present value of the costs is \$272 million and of the benefits is \$682 million, a present worth of \$410 million. Similar calculations for the other levels of student capacity produce the chart of costs and benefits shown in the top part of Fig. 3. This is, in turn, presented

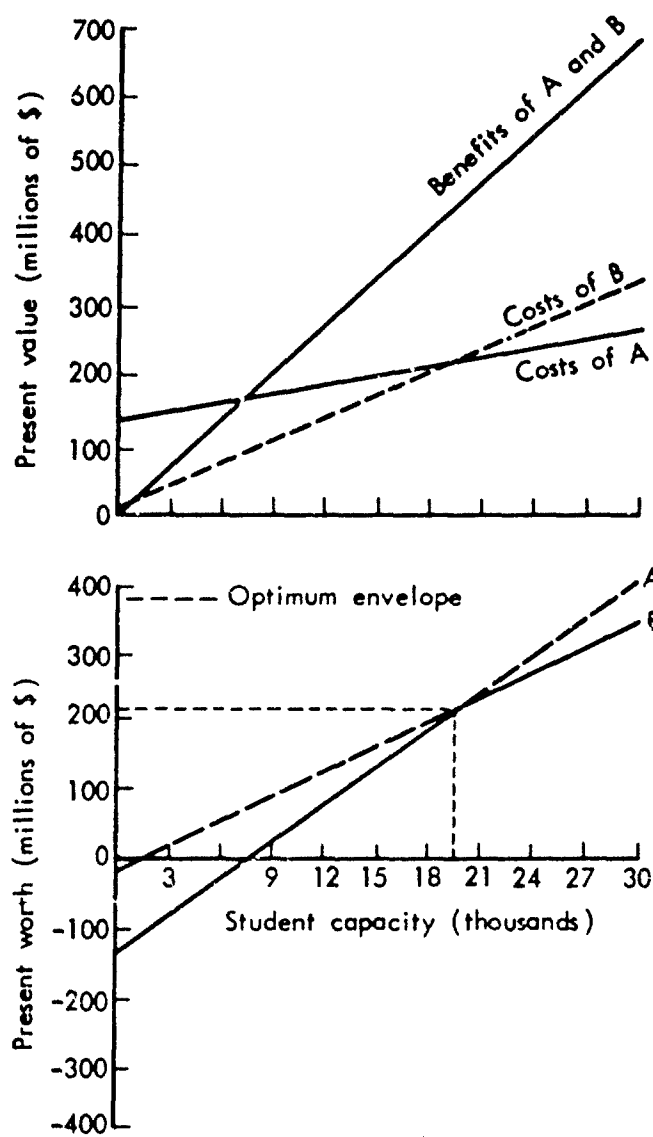


Fig.3--Present worth of alternative systems A and B
(6% discount rate)

in present worth terms on the bottom part of Fig. 3. Because of the shape of the time streams of cost and benefits and the discount rate selected, there is a shift in the cross-over point for preferring System A to System B from the undiscounted case. The shift now occurs at about 20,000 students, rather than 13,600 students. Both systems have a negative net worth under about 800 students and System A continues to have such for up to 7500 students. Again, one can draw an envelope showing the best course of action (all other things being equal!). If money is worth 6%, it would not pay to invest in the program for less than 800 students. System B would maximize returns for student capacity up to 20,000 and System A would maximize returns thereafter. Conversely, funds of about \$225 million or more should be invested in System A and funds of less than that in System B.

IV. FEATURES OF SYSTEMS COST ANALYSIS

Now that we have reviewed the way in which system costs are used in cost-benefit analysis, let us turn to a discussion of the distinctive features of systems cost analysis. What are the characteristics which set it apart from other types of cost analysis? While any list of features is somewhat arbitrary, I believe that the more important of these are as follows:

1. End-product orientation.
2. Extended time horizon.
3. Incremental costing.
4. Life cycle costs.
5. Dollars as the measure of resources.
6. Analytical approach and statistical techniques.

1. End-product Orientation. Cost-benefit analysis has as a basic principle the identification and analysis of a "system"--a means by which an objective may be accomplished.* The PPBS term is "Program Element--an integrated activity which combines personnel, other services, equipment and facilities."**

* See Quade [4], p. 13.

** See BOB Cir. 66-3 [5], p. 4.

The end-product orientation of cost analysis reflects this "systems" approach. It is a basic principle of systems cost analysis that requirements for diverse resources be identified and associated with end-products such as the new school systems in the case of our illustration, or transportation systems such as a supersonic transport or a turbine train. The immediate problem is to identify all costs associated with the selection of a particular system. This reflects the view that decisions must not be based solely on the cost of the major equipment, or solely on personnel requirements, or on any other particular resource associated with the system, no matter how critical its role. Instead, the cost of a system should reflect the total resource impact of the decision relating to that system. Identifying and indicating the magnitude of all relevant costs of a particular system or course of action is the basic purpose of a cost estimate.

2. Extended Time Horizon. As previously stated, cost-utility analysis is a tool for long-range planning, for "taking a long view and a wide view." In particular, development decisions are often required from five to ten years before a system can be brought into being. The span of time covered in a cost analysis must be sufficiently long to cover such lead times. Further, the time horizon must cover the full period of a system operation and for the period of its benefits. In our case study, the benefits extended for ten years after the operation ceased, and, with a three-year development and investment period, a total of 23 years was involved. The extended time horizon, therefore, becomes an integral part of cost analysis in its application as a technique for longer range planning.

I might point out that this extended time horizon has important implications for the development of cost estimates. It brings with it a great deal of uncertainty, and the farther out in time the analysis is addressed, the greater the uncertainty. Cost analyses of systems envisaged for ten years in the future, for example, often constitute costing equipment never before produced or new operations never before attempted. Involved are new materials, new manufacturing processes, new training concepts--all of which make their costing difficult and

the resulting estimates uncertain. Thus, stress is placed on the comparability of estimates rather than on their absolute values.

3. Incremental Costing. Cost analysis, like cost-benefit analysis which it serves, can be viewed as an application of the economic concept of marginal analysis. The analysis must always move from some base that represents the existing capability and the existing resource base. The problem is to determine how much additional resources are needed to acquire some specified additional capability, or conversely, how much additional capability would result from some additional expenditure. It is, therefore, the incremental cost that is relevant.

The economic concept of marginal analysis is to be distinguished from the accounting concept of associating total costs, including an allocated share of indirect expense, to an end item. Ideally, the incremental cost of a system is the difference between two total programs, one with the system and one without it. In the military we refer to the costing of total programs as "Total Force Structure Costing" and I will address this subject later. We have considerable experience in DOD in defining the Strategic Forces Program and can develop the total program with and without a new strategic system reasonably well. In our illustrative case, we could perhaps define the Program as being government outlays for job placement training in area X. Figure 4 illustrates the ideal method of measuring the incremental cost for System A-- by comparing two total programs.

Now it is quite often difficult to precisely define the total program (or total programs of an agency) and we resort to making reasonable assumptions about the total programs and concentrating on the single systems under analysis. We did this in our illustrative case by assuming that no other program except the job placement program was affected. It is possible that, had we had the ability to project all the programs, we could have observed decreases in the costs for police and emergency hospital operation (less crime), but, say increases in the cost for parks and recreation (more disposable income).

Sunk Costs. In measuring incremental costs, we must be careful to exclude "sunk" costs (costs expended in the past). Costs which have been expended in the past are simply not relevant to the question,

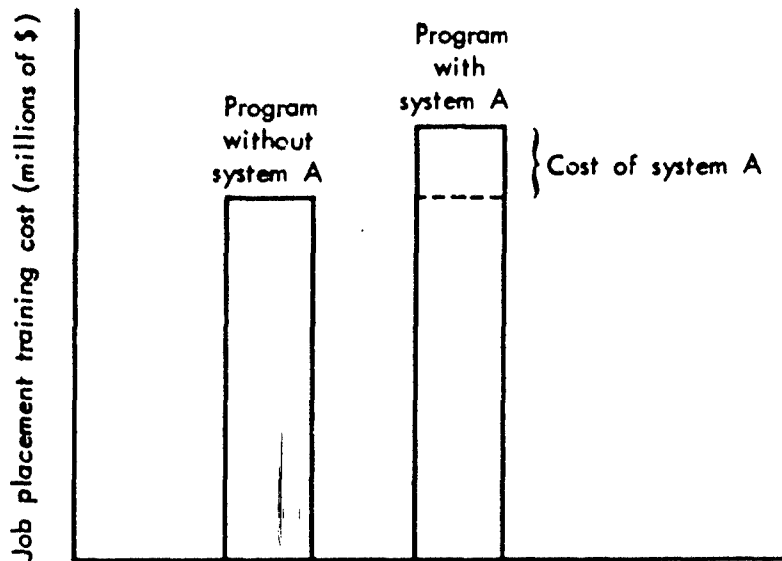


Fig.4—Incremental cost of system A

"What will it cost in the future to acquire a future capability?" No matter how "unfair" it may seem, we should not include the past costs, say for older systems, regardless of how much money is involved. For example, we have invested several billion dollars in the SAGE air defense system. If the Federal Aviation Agency (FAA) wants to estimate the costs of an air traffic control system for 1970 which would include the present SAGE system, only the future outlays to develop, buy, and operate new equipment and facilities or to modify and operate existing ones should be considered. The several billion dollars spent in prior years should have no bearing on the decision regarding a future system.

Now I did not say that the resources acquired by the past expenditures on SAGE should be excluded from our analyses. Should sunk costs result in inheritable assets (resources which will become available only to the system under analysis) the sunk costs of those assets should be excluded. Inheritable assets can result from sunk costs on many systems, not just the ones under obvious consideration, and it is

this reason that explicitly costing a total program or total agency is best because all systems can be examined and a better picture of resources available for other systems revealed. Conversely, all the systems competing for these assets are revealed. Thus a truer picture of net asset requirements is shown.

Let me illustrate these points. Recall that System A had estimated development costs of \$150 million for some complicated computer programs and equipment. If the study of this problem was delayed two years and, meanwhile, \$30 million per year had been invested in the program, then, at the time for decisionmaking, the relevant costs would be \$90 million (\$150 million less \$60 million) assuming no change in the total program estimates. The \$60 million would be "sunk" and irrelevant. Or, as concerns today's situation, it is possible that \$100 million has already been expended on the system and that the \$150 million represents future costs of a development program whose total cost will be \$250 million.

Regarding inheritable assets, let us assume that a System C does exist now and has a capability of training 10,000 students, although it is not judged worthy of expansion. It has 50 teachers per school and a 20:1 student-teacher ratio. While the buildings and equipment could be used by System B with 2000 students per school, the capacity for System C is only 1000 students. System A cannot use System C facilities because it needs completely new facilities for its advanced equipment. If we assume that \$3.0 million per school are saved if System B utilizes the facilities of System C, the system costs (in millions) become:

	System A	System B		System C
		1st 10	Additional	(10 Schools)
Development	\$150.0	\$10.0		--
Investment/school	5.0	1.0	4.0	--
Operations/year/school	1.5	3.0	3.0	1.0

The charts on Fig. 1 then become as shown on Fig. 5. Unfortunately, the investment savings for System B were not very significant, so that the break in the system costs after school #10 is not sharp. We note that System C's cost curve stops at unit 10 because we do not plan to

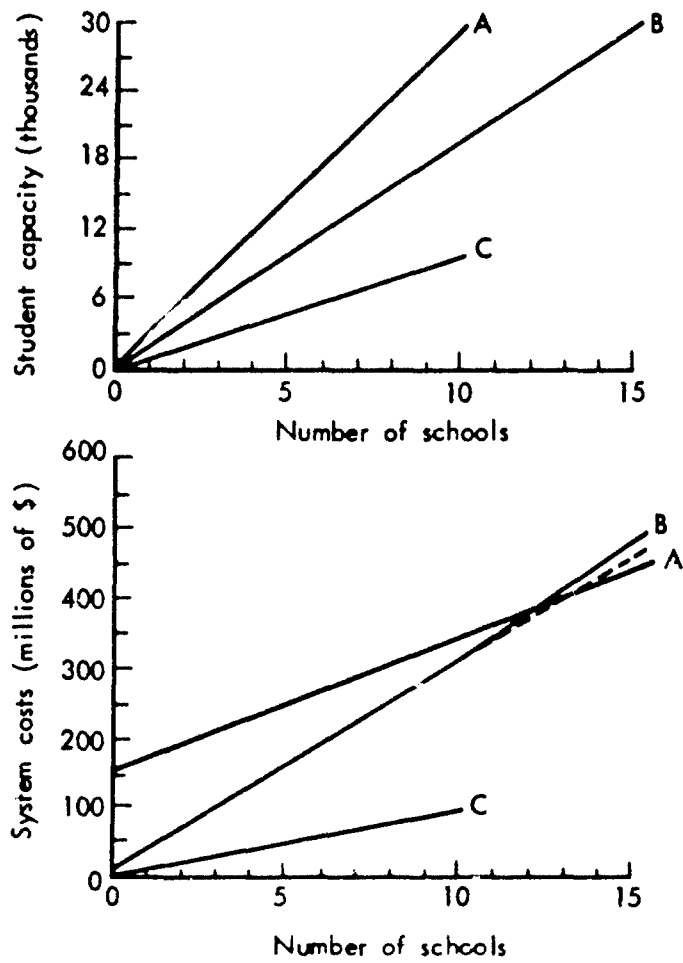


Fig.5—Student capacity and system costs versus number of schools for alternative systems A, B and C

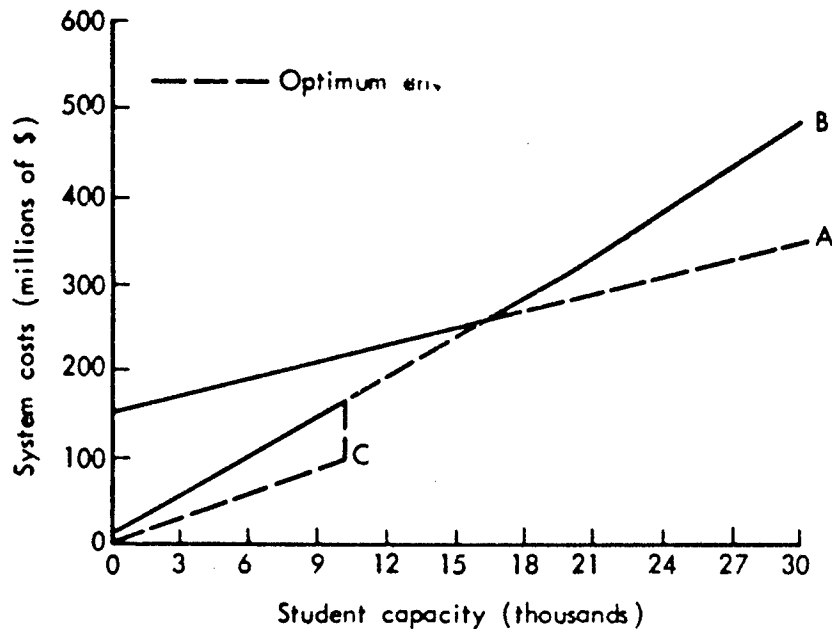


Fig.6—Student capacity versus system costs for alternative Systems A, B and C

expand it. System A's cost curve is unchanged from the previous situation because it cannot inherit any resources, and System B's cost curve breaks after unit 10 when facilities can no longer be inherited.

In case you are interested, the envelope of optimum cost to benefits now looks like Fig. 6. System C is preferred for all student loads up to 10,000, System B from 10,000 to 15,800 and System A from 15,800 to 30,000. Conversely, for budget levels of about \$165 million or less, System C is preferred, (even though you can spend only \$100 million on C); System B from \$165 million to about \$255 million; and System A thereafter.

4. Life Cycle Costs. One distinctive feature of systems cost analysis is the use of cost categories. System costs are identified and grouped as (1) research and development, (2) investment, and (3) annual operating costs. These cost categories reflect the life cycle

approach of cost analysis. Life cycle costing results from the principle that the funds necessary to initially undertake a program are not the primary consideration, nor are the funds required in any particular time period; but a decision to undertake a particular course of action should take into account its total cost impact over time. The cost of developing the system must be accounted for; and the cost of procuring the system, and also the cost of operating it as a component of the force, must be taken into consideration. Definitions of the cost categories used in military studies are as follows:

1. Research and Development. Costs primarily associated with the development of a new system or capability to the point where it is ready for introduction into operational use. This category includes prototype equipment and test equipment used in a development program.
2. Investment. Costs beyond the development phase to introduce new systems or a new capability into use.
3. Operations. Recurring costs of operating, supporting, and maintaining the system or capability.

I already have been using these categories in my illustrative case. You have perhaps already noted the behavior of these categories as a function of system size. A system's research and development costs are one-time costs and are, in effect, a function of the nature of the system. Research and development costs are essentially insensitive to the number of units of the system that will be procured or the length of time that the system will be in operational use.

Investment costs are a function of the number of units planned for the system. The greater the number of units to be introduced into the program, the higher the investment cost. Such costs are essentially one-time costs per unit.

Operating costs depend on both the number of units in the program and the length of time that such units are operated, supported, and maintained.

These three distinct categories are useful in making program decisions.* The R&D costs are concerned with development decisions and the choice among feasible alternatives. We can develop System A and thus have it on the shelf but we do not have to procure it. The investment costs concern the extensiveness of the system's employment or the relative importance that the system should occupy in the program. Having once developed System A we can procure a capacity of from 1 to 10 schools depending upon our situation. The operating costs concern the manner and the length of time that the system should be operated. We chose to operate them 10 years in our example but we could have varied this.

Figure 7 depicts cost category patterns over the life cycle of a system. The cost category levels are illustrative of typical patterns for individual military systems.

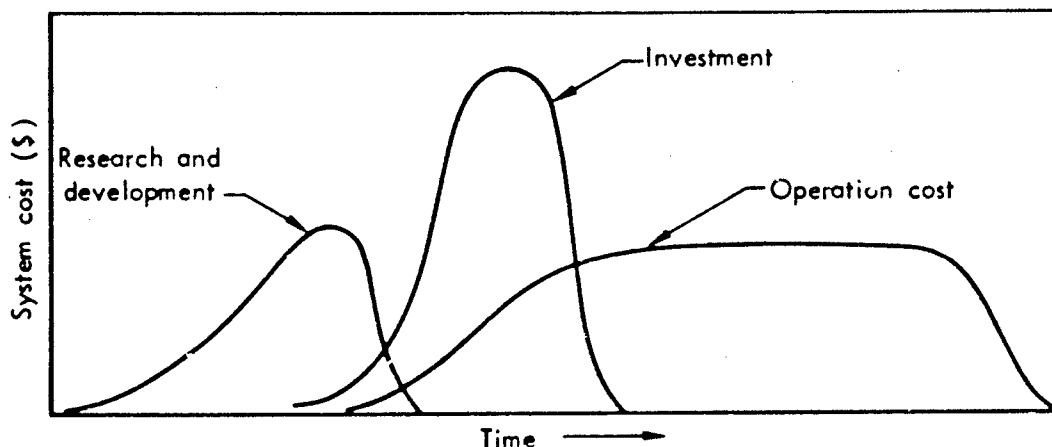


Fig.7—Life cycle costs: Illustration of system "Life Cycle" identification plotted against time

5. Dollars as a Measure of Resources. The purpose of cost analysis is to develop estimates of future resource requirements for systems. Resource requirements are stated in terms of equipment, personnel, real

*The R&D decisionmaking process in DOD has become somewhat more sophisticated in recent years. More cost categories are thus appropriate for decisionmaking in DOD; e.g., (1) Conceptual; (2) Definition-Phase IA; (3) Definition Phase IB; (4) Definition Phase IC. See AFSCM 375-5, [6].

facilities, supplies, etc. A total system cost cannot, however, be developed by summing over such a heterogeneity of resources that make up a system. Nor could understandable comparisons be made between systems if their costs were expressed solely in terms of varieties of real resources. The dollar cost of such resources can serve the purpose, and is the measure selected for cost estimating.* Of course, in estimating a system, we want to spell out the important resources in terms of their quantities. Critical resources, whose supplies are quite limited, such as technical manpower, should be given separate attention in the analysis.

Further, constant dollars are nearly always used.** Rarely is an attempt made to predict future price level changes in comparing or evaluating alternatives in cost-benefit studies. Such predictions are extremely difficult to make and many problems remain to be solved. Costing guidelines for DOD studies specify that constant dollars will normally be used.

6. The Analytical Approach and the Use of Statistical Techniques. Systems under study are often technically advanced far beyond our range of experience. In the early consideration of such systems, specifications cannot be defined with exactness. As mentioned earlier, many of the components of future systems have never been constructed before, and no cost experience exists. To project costs beyond the range of experience places the emphasis on analytical processes. The use of statistical methods assists in this analysis. Data on past and existing systems are analyzed statistically to derive relationships between costs and the system characteristics known at the outset. For example, for a computerized teaching machine for System A, such characteristics could be performance characteristics such as computational speed or physical characteristics such as memory size. The purpose of such analysis is to develop cost-estimating relationships (CERs) suitable for projecting costs of future systems. Scatter diagrams, regression analysis, and correlation analysis are examples of statistical techniques useful in the development of such cost-estimating relationships.

* For a more detailed discussion, see Hitch, [7], pp. 26-28.

** Prest and Turvey [2], p. 691.

V. STEPS OF COST ANALYSIS

Now that we have reviewed the salient features of systems cost analysis, let us look at the process of developing cost estimates. There are no set rules or fixed procedures which, if followed, would insure the successful accomplishment of a reliable system cost estimate. However, there is a general approach to system cost estimating that can be described. This approach can be viewed as a series of steps in the development of a cost estimate. First, let us look at a summary of these steps:

1. Defining the problem. What is to be costed and under what context and ground rules?
2. Obtaining a specific systems description--in terms of:
 - a. Equipment description.
 - b. Operational concepts and objectives.
 - c. Location of facilities.
3. Collecting data for use in preparing the estimates.
4. Converting the systems description information into a statement of resource requirements--in terms of:
 - a. Equipment.
 - b. Facilities.
 - c. Trained personnel.
5. Translating the statement of resource requirements into costs, using as a vehicle a comprehensive chart of cost elements, which highlights the significant cost areas for that system.
6. Presenting the cost estimates in terms suitable for the decisionmaker, and dealing with cost sensitivity.
7. Documenting the analysis.

Although these steps are outlined as though they are sequential and discrete, there is, in the practice of developing cost estimates, a considerable amount of indefiniteness between steps and a good deal of looping back as the study progresses. For example, the derivation of cost estimates may cause the system analyst to reconsider alternatives, thereby redefining the problem for the cost analyst. The derivation of the estimate could also identify needs for additional data.

Further, documentation efforts to some degree must be undertaken at the very beginning of the study. It should be kept in mind, therefore, that these steps in reality are the types of effort performed in the development of a cost estimate. We will now expand on each of the seven steps listed.

1. Defining the Problem. This step centers on the relationship of the cost analyst to the director of the cost-benefit study. Here the task is to assist the director in establishing the proper analytical framework from a "cost analysis" point of view. Are the right questions being asked? What concept of cost properly fits this problem? Etc.

In insisting that the cost analyst assist in establishing the proper framework you might feel that I have strayed from the path of "making a cost estimate" into the field of the system analyst, but I cannot overstress the importance of this phase. The success of the entire study literally depends upon good problem formulation.

A major product of the "problem definition" phase will be the cost ground rules to be used in the study. The ground rules, in effect, represent the assumptions underlying the study.* Examples of study ground rules are as follows:

- (a) Kind of cost index to be used. (Example: R&D, investment and n years of operating cost where $n = 5$ or 10 in current Air Force studies.)
- (b) Date as of which all prior costs will be considered sunk costs. (Example: FY 1967.)
- (c) Rules regarding discounting to a present value.
- (d) Rules regarding costs of other agencies. (Example: for DOD, the nuclear warhead costs incurred by the Atomic Energy Commission.)
- (e) Special rules regarding indirect costs which may vary with the system, such as support personnel on a facility which houses several systems.

* Appendix 1 contains an excellent example of general cost ground rules oriented, of course, to DOD studies. The Costing Guidelines for DOD Cost-Effectiveness Studies, OASD (SA), Resource Analysis, May 1, 1966, are reproduced for convenient reference.

2. Obtaining a Specific Systems Description.^{*} This step centers on the relationship of the cost analyst to the systems analyst. The problem definition phase requires very close contact between the cost analyst and the systems analyst so that the systems to be costed can be described adequately for costing purposes. That is, the systems to be costed must be described in terms of their cost-generating properties. This includes information on:

- . Equipment description.
- . Operational concepts and objectives.
- . Location of facilities.

Systems descriptions needed by cost analysts can differ considerably from those used by systems analysts. The cost analyst needs a description of the system oriented to his own "tools," i.e., the chart of cost elements and the format of his input data, such as cost factors and cost estimating relationships.

For example, in an aircraft system, the flying hour program of aircraft is usually important for costing because a number of estimating relationships are stated as a function of flying hours, while many performance data are normally of lesser importance. The systems analyst on the other hand is usually more interested in performance aspects of the system, say, the accuracy of the navigation equipment. Hence, the required system description must be sensitive to the requirements of the cost analyst.

DOD cost analysts use informal checklists to assist them in developing the system description. I am not acquainted with any published checklists for non-defense agency studies, so I must use DOD examples. These checklists vary (1) by type of system--e.g., aircraft, missile, space ship--and (2) by the phase which the system has reached at the time it is costed--e.g., conceptual, development, acquisition, operation. Estimating techniques will vary with the phase of a systems development, and, therefore, so will the questions that must be answered.

^{*}For a further discussion, see M.V. Jones, [8], pp. 38-54.

It is essential that the checklists which the cost analyst uses provide information in the form and terms for which cost-estimating relations and factors are available or can be readily developed. For example, in costing aircraft an estimating relationship may require such data as empty weight, maximum speed at altitude, and maximum engine thrust. The checklist used to assemble a system description must help insure that answers to these questions will be obtained. Other data, such as wing span or wing area may be interesting, but irrelevant.

3. Collecting Data. Given the system description information and the study ground rules and assumptions, the cost analyst must then proceed to gather the necessary data in preparation for estimating the resource requirements and the dollar costs. It is difficult to describe beforehand in a precise way the means of handling data needs for specific projects. This is so primarily because data needs and availability vary considerably from system to system. Such variations stem for the most part from the status (or phase) of the system, i.e., whether the system is in the conceptual, development, procurement, or operational phase. As a system progresses through the various phases--from the conceptual to the operational phase--more and more data become available. In the early phases, the system can usually be described only in general terms but as it evolves and enters the later phases, contractor data and data from various other sources become available in richer detail.

Although the comments regarding collecting data have focused on its collection for a specific system, there will exist in a cost organization an on-going activity of data gathering that is not geared to a specific system but to the general area of interest of the department.

The collection of much data normally will begin long before a specific project is undertaken. This is necessary because a prime requisite to cost analysis is a satisfactory data base. It is important to have on hand as much historical data as possible not only on "cost" (or dollar) data, but data on performance specifications and design characteristics as well. Further, these data must be analyzed for causal factors so that we can use these historical data to estimate the costs of future systems based on their assumed characteristics. We must start with a realistic base as we look to the future.

Each cost analysis organization should have a cost library (sometimes called a "Data Bank") which would provide the following:*

- (a) A means for indexing and classifying cost and related data.
- (b) A physical facility for the storage of data.
- (c) A means for ready access to the data by the analyst.

In sum, an adequate data base occupies a critical place in the cost analysis process. Preparations to meet data requirements must be started early, and data must be maintained continuously to be available for the diverse needs of cost estimating.

4. Converting the information into a statement of resource requirements. The cost analyst takes the data contained in the system description and, armed with the study cost ground rules and assumptions, turns to his cost data base to develop estimates of the resource requirements in terms of equipment, facilities, and trained personnel. Discussion of estimating techniques is covered in general terms in the next topic, "translating the resource requirements into costs."**

Equipment requirements must account for the total procurement of units including not only the basic operational units but those set aside for testing, for use by training organizations, and for stockage to permit maintenance of operational units. In our illustrative case, we would have to buy not only the more obvious operational units for the 10 schools, but also sufficient units for testing during the R&D phase, one unit for training the equipment operators and teachers, and the equivalent of several units to replace parts as they fail.

Facilities should include both operational and support facilities. For our sample case we assumed the schools would be located in a metropolitan area so support facilities would not be required. However, if they were located in an undeveloped area, it might be necessary to provide additional facilities for laundry, fire protection, maintenance, etc.

Personnel requirements for our sample case would probably be estimated by type of skill. Teachers would, of course, be a critical

*For a description of one such Data Bank, see Slivinski [9].

**For detailed estimating procedures for this step (oriented to DOD systems), see Large [10], especially Chaps. VIII, XI, and XII.

resource for both Systems A and B. Perhaps some categories of teachers would become a very critical resource in terms of a limited supply situation.

5. Translating the statement of resource requirements into costs.

This step in the process is concerned with the actual calculation of the dollar estimate. Cost estimates are developed within the framework of cost element lists. Cost elements are subdivisions of the three cost categories: R&D, investment, annual operating. All costs associated with a system must be identified and included; hence, availability of a good cost element list helps to attain this objective. There must be flexibility in the makeup of the cost element list. It must be adapted to the type of system, the nature of the problem, and the type of analysis. However, its basic function is to identify and account for all elements of cost associated with the system. The ideal cost element list highlights the key features of the system, and, at the same time, permits maximum use of data collected from past systems. The list must also be translatable into budgeting and programming terms.

A cost element list used by The RAND Corporation for its studies of an ICBM system is shown on the right-hand column of Fig. 8. The figure also illustrates the major system description information and the format for displaying the estimated resources required. To calculate dollar costs for each cost element on such a cost element list, the cost analyst chooses the best available estimating methods from those listed below (assuming that a "Bill of Materials" estimating approach is not used).*

- a. A catalog price. An item to be costed is identified as an off-the-shelf resource and the appropriate catalog price plus adjustment is used. For example, most of the equipment in the sample System B was assumed to be off the shelf, in contrast to the specialized equipment of System A. Appropriate quantities of System B equipment would be multiplied by the prices in dealer catalogs.

* For a further elaboration on estimating methods, see AFSCS 173-1 [11], pp. 6-1 to 6-11.

COST ESTIMATING PROCESS FOR AN ICBM WEAPON SYSTEM

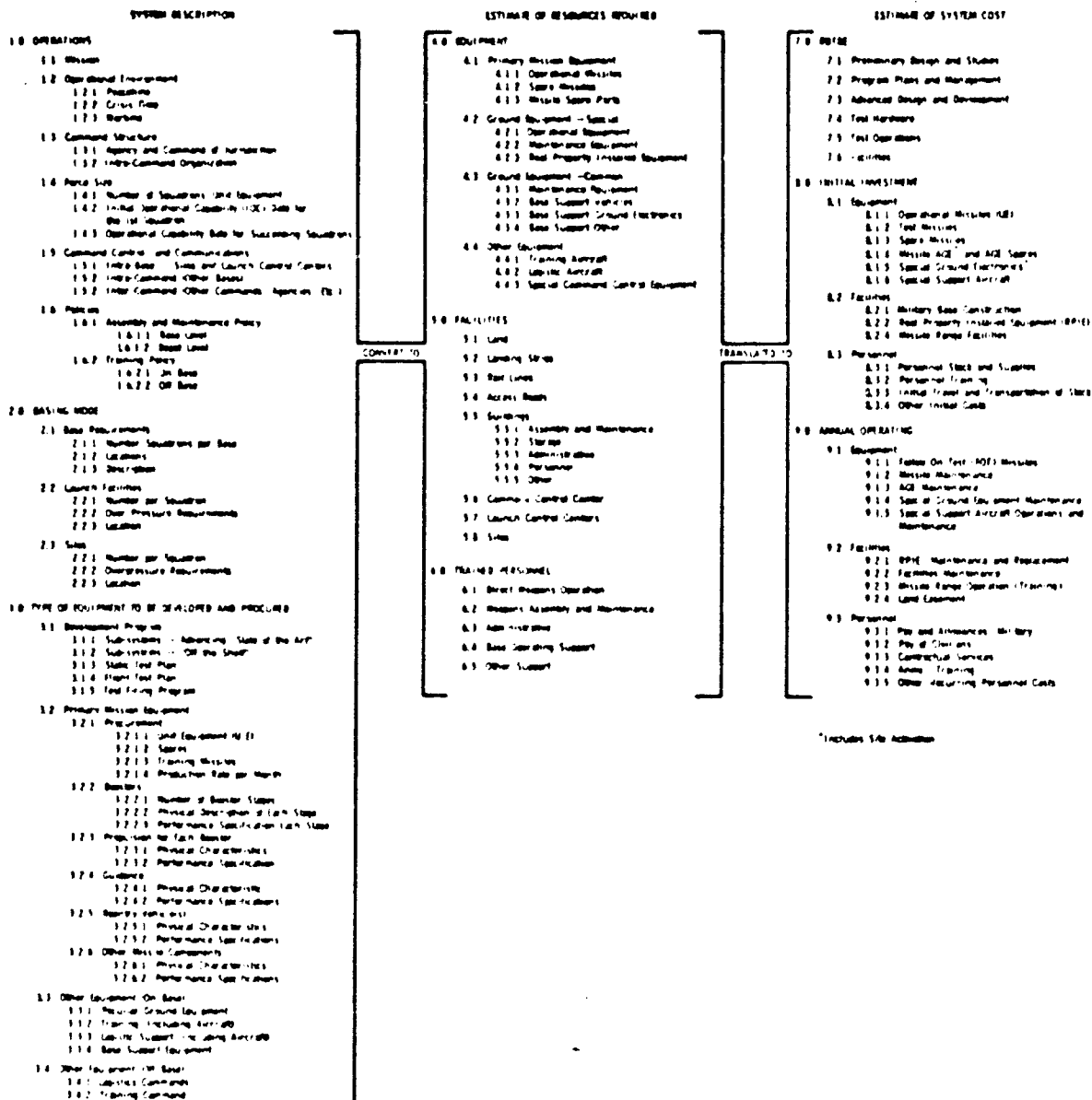


Figure 3

Source: Prepared by A.J. Tenzer and J.J. Kermisch.

- b. A specific analog. An item to be costed is identified as being analogous to some specific prior system and costed using that system's experience. For example, System A equipment might conceivably be similar to that used by System Z installed three years ago in another area.
- c. An estimating relationship. I have already touched on estimating relationships, commonly known as ERs, without formally defining them. An ER can be defined as a mathematical expression that describes, for estimating purposes, the cost of an item or activity as a function of one or more independent variables. This form may vary from simple linear relationships to more complex forms. For example: $\text{Cost} = a + bx$ where X is an independent variable and a and b are parameters whose values are to be determined from the data. When a is equal to zero, the estimating relationship has the typical form of a Planning Factor such as \$1000 per man or \$500 per flying hour. A slightly more complicated example is:

Depot maintenance cost per flying hour for bombers:*

$$\text{\$} = 9.20 + 3.35X$$

where X = airframe wt in thousands of lb.

A rather complex form would be:

$$\text{Cost} = ax^b y^c.$$

An example of this form is:

Non-recurring airframe engineering costs:**

$$\text{\$} = 14 S_K^{0.54} W^{0.88}$$

where S_K = max speed in kn

W = airframe wt in lb.

*Large [10], p. IV-24.

**Hatry [12], p. 16.

- I will not attempt in this paper to discuss the derivation of ERs, but the reader is referred to Large [10], Chaps. IV and V.
- d. An expert opinion. An expert in some functional specialty (e.g., personnel) or field of technology (e.g., salary administration, computers) provides the cost estimator with an estimate of the cost of the item or of the resources in the new system.

Learning Curve. As a final remark concerning estimating techniques, I would like to touch on the learning curve. The learning curve or progress curve has been widely used in the aerospace industry and DOD as a technique for estimating equipment costs. The theory of the learning curve is that as the total number of units produced doubles, learning occurs such that the cost per unit declines by some constant percentage. For example, an 80 percent learning curve would indicate that the unit cost of the 100th unit would be 80 percent of the unit cost of the 50th unit, and so on. Mathematically, this is indicated by the expression, $\text{cost} = ax^b$ where a = cost of the first unit, x = the unit whose cost is desired, and b = the slope of the learning curve.

Figure 9 indicates a typical unit cost curve and its relation to cumulative average costs and cumulative total costs.* In estimating advanced systems, the cost analyst would generally first derive some point on such a curve, such as the cost of the 100th unit and then develop a learning curve for the system (or component).

The estimates for resources and dollars for Systems A and B might look like those shown on Table 2. For illustrative purposes, I have used very simple estimating relationships for all cost elements in the sample. Perhaps the only cost element needing elaboration is Replacement Training. For it I have assumed that 10 percent of the teachers leave System A each year, and 12.5 percent leave System B. These teachers must be replaced and the new ones must receive the special training required for each system.

*For an excellent summary of learning curve theory, see Brewer [14].

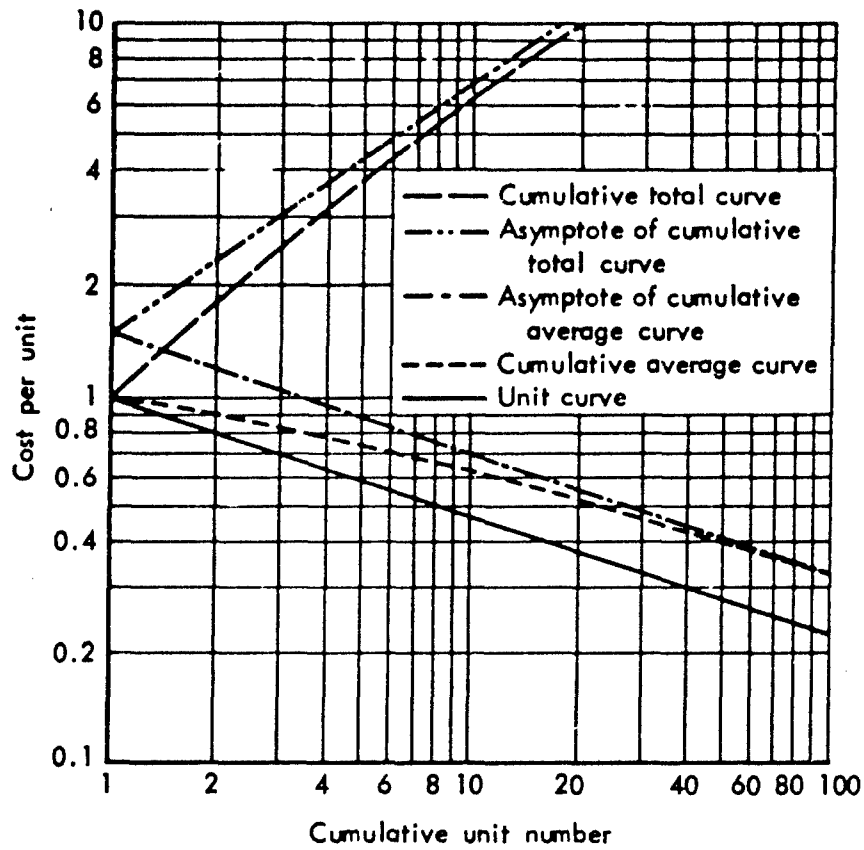


Fig.9—Progress curves resulting from the assumption of a linear unit curve on logarithmic grids

Source: Asher [13], p.23

Table 2

RESOURCE REQUIREMENTS AND COST ESTIMATES FOR
ALTERNATIVE SYSTEMS A AND B
30,000 STUDENT CAPACITY SYSTEMS
(Costs in millions of dollars)

Resources		
School buildings	10	15
Sets of major equipment:		
Test-prototype	<u>2</u>	--
Operations	10 (specialized)	15 (off-the-shelf)
Training	1	1
Spares	<u>4</u>	<u>6</u>
Total production sets	<u>15</u>	<u>22</u>
 Personnel:		
Teachers	500 (50 x 10)	3000 (200 x 15)
 Cost Estimates		
Research and Development:		
Engineering development and software	100.0 (14 months @ 7.1)	1.0 (16 months @ .6)
Prototype fabrication	30.0 (2 @ 15)	1.0 (off-the-shelf + mod.)
Test program	<u>20.0</u> (10 mos @ 2.0)	<u>8.0</u> (8 mos @ 1.0)
Total R&D	<u>150.0</u>	<u>10.0</u>
 Investment:		
Buildings	15.0 (10 @ 1.5)	15.0 (15 @ 1.0)
Equipment	25.0 (15 @ 1.7)	15.0 (22 @ .7)
Training of teachers	5.0 (500 @ .01)	24.0 (3000 @ .008)
Supplies	<u>5.0</u> (10 @ .5)	<u>6.0</u> (15 @ .4)
Total investment	<u>50.0</u>	<u>60.0</u>
 Annual Operating:		
Building maintenance	1.5 (10% of inv.)	1.5 (10% of inv.)
Equipment maintenance	5.0 (20% of inv.)	3.0 (20% of inv.)
Supplies	3.0 (.3/school)	7.5 (.5/school)
Salaries of teachers	5.0 (500 @ .01)	30.0 (3000 @ .01)
Replacement training of teachers	<u>.5</u> (500 x 10% x .01)	<u>3.0</u> (3000 x 12.5% x .008)
Total annual operating (1 yr)	<u>15.0</u>	<u>45.0</u>
Total annual operating (10 yr)	<u>150.0</u>	<u>450.0</u>
 TOTAL SYSTEM COSTS (10 yr)	<u>350.0</u>	<u>520.0</u>

6. Presenting the cost estimates. To cover this important step I wish to describe three aspects of how the cost analyst communicates with the users of his estimates.

- (1) The presentation form must be appropriate for the decision to be made.

It is important that the analyst find ways to summarize and to distill the results of his analysis so that the user can quickly grasp the essence of the findings. Graphic presentation, summarizing and highlighting the costs in meaningful ways, is highly desirable, with only the most essential footnotes or "boiler plate" contained thereon. Recall Figs. 1 and 2 of the sample, how they highlight various aspects that a decisionmaker would want to know.

- (2) The presentation form also must be translatable into programming and budgetary formats.

In addition to the presentations oriented to the decision to be made, it will often be desirable to present findings in the format of the programming system, and possibly of the budget itself (although one should caution that these are not budgetary estimates in themselves). Therefore, the chart of cost elements developed for estimating purposes must be translatable into more standardized financial management terms, such as budget appropriations.

- (3) The sensitivity of the costs to alternative assumptions must be presented.

A review of the estimates by cost element will quickly indicate to the decisionmaker the areas of major cost significance for one set of estimating assumptions. It is most important that, to the extent possible, the cost analyst present charts which indicate the sensitivity (and insensitivity) of costs to variations in the study assumptions. Three fundamental types of sensitivity checks will generally be applicable to the results of most cost-effectiveness studies. They are:

- . Sensitivity to basic system or project requirements,
- . Sensitivity to uncertainties in estimated or extrapolated data, or
- . Validity of simplifying assumptions or arbitrarily fixed variables.*

An example of sensitivity analysis is presented in Novick [1], pp. 115-119. Figure 10, borrowed from that study, illustrates a sensitivity analysis of a low altitude penetrating missile launched from a long endurance aircraft on station near enemy territory. Total system cost is charted as a function of three variables: force size, average flyout distance from base to station and estimated weight of the missile. Total system cost is very sensitive to the missile range (and, hence, gross weight), and it is fairly sensitive to whether the optimistic or conservative estimate of the weight versus range curve is used. On the other hand, total system cost is relatively insensitive to average flyout distance from base to station. This type of information can guide the decisionmaker in making decisions about allocation of research efforts (to reduce missile weight, for example) and operational deployment considerations (it doesn't cost much to fly longer distances, allowing the use of bases further from the enemy).

Toward employing sensitivity analysis to our school sample, let us assume that there is considerable doubt that System B's team concept can be made so efficiently that only 200 teachers are needed per school (a 10:1 student-teacher ratio). Assume further that possibly 300 teachers or even 400 will actually be required. These assumptions are considered in the total system costs which are displayed on Fig. 11. as a function of teachers per school. In this figure total system costs are shown to be quite sensitive to the number of teachers. For example, costs for 30,000 students rise from \$520 million to \$697 million and \$874 million for 300 and 400 teachers, respectively. (Recall that during our discussion of sunk costs, system B's costs were relatively insensitive to the inheritance of facilities from System C.) Let us also assume that there is a possibility that the teachers required for

* WSEIAC Final Report [16], pp. 116.

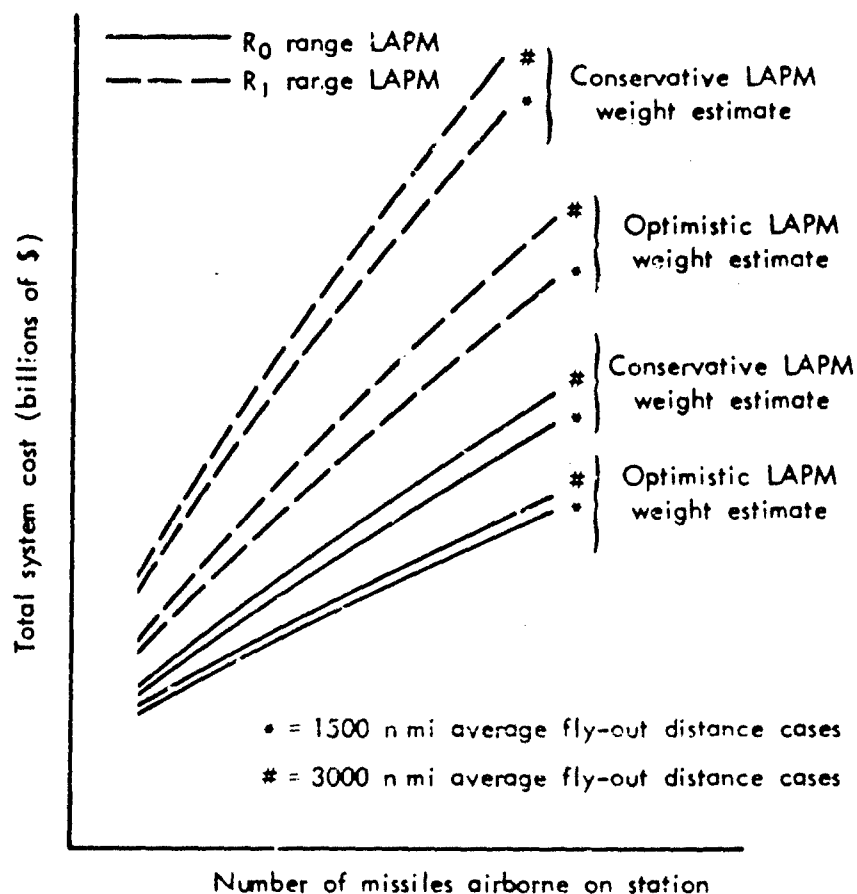


Fig.10—Total system cost versus force size for various cases

Source: Novick [1], p.118

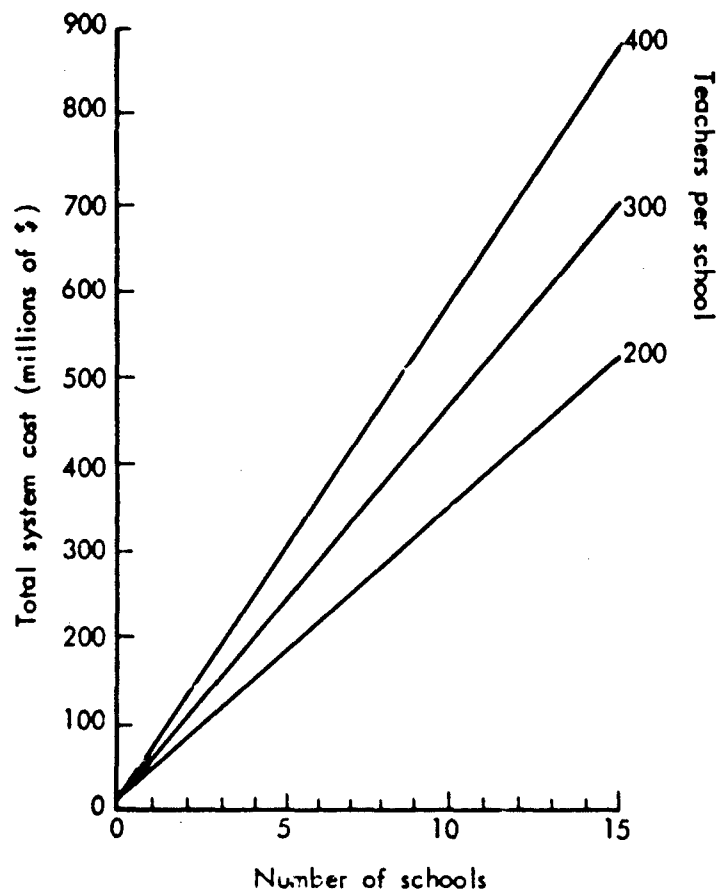


Fig.11 — System costs versus number of teachers per school system B

System A could double to 100 teachers per school instead of 50. In this case, system costs for 30,000 students rise from \$350 million to \$410 million.

The cost-benefit curves under these assumptions are plotted on Fig. 12. Cross-over points for varying numbers of teachers per school now occur as follows:

System B	System A		Costs (Mil.)	
	Student Capacity			
	50 ^a	100 ^a	50 ^a	100 ^a
200 ^a	13,600	16,700	242	295
300 ^a	8,600	9,900	207	236
400 ^a	6,400	7,000	193	210

^aTeachers per school.

System B is preferred for systems whose student capacity or system cost is equal to or less than that shown in the above table. System A is preferred for larger values.

How would a decisionmaker use this information about cost sensitivity? He would first look for regions where one system was clearly dominant. In our example, System B is dominant in all cases for student capacities under 6400 and for system cost levels under \$193 million. System A is dominant in all cases for student capacities over 16,700 and for system cost levels over \$295 million. For values in between these points, neither system is dominant. Selection of A or B is influenced by the uncertainty of how many teachers per school are needed. Unfortunately, we just don't know what the decisionmaker would, or should, do in this situation. His selection would be influenced by such factors as his guess as to the likelihood that each possible number of teachers per school would occur, his personal value systems, his attitude toward risk-taking, and other factors. The point is, however, that because we have this region of uncertainty, the decisionmaker will be much better off given this information on cost sensitivity than if he is not. Analysts should not, in effect, make the decision themselves by presenting decisionmakers with only one set of possible outcomes, instead of the six in our example

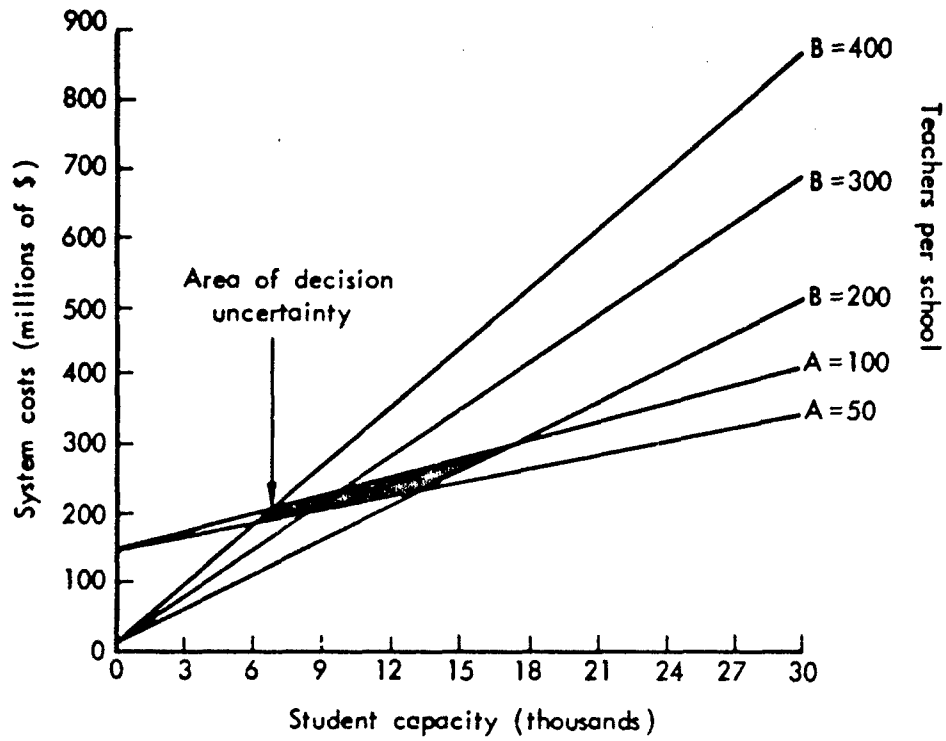


Fig.12— Sensitivity analysis—system costs versus number of teachers per school for alternative systems A and B

7. Documenting the Analysis. A proper documentation of the study is important to both the cost analyst and the users of estimates. Documentation includes not only the published estimates and their derivation but also an orderly, cross-referenced assembly of the detailed working papers used by the analyst in developing the estimates. It provides the analyst with a record of the study and also serves as a source for material to be used in later studies. Studies themselves serve as valuable sources of data for inclusion in the data bank.

Documentation is particularly important to the user of the cost estimate in his evaluation of the study. Documentation should reflect the analytical approach. It should openly and clearly describe the procedures, data, and sources used. It should also permit the estimates to be reproduced by following the process and facilitate the review and evaluation of data, sources, inputs, and methods.*

The DOD Costing Guidelines contained in Appendix 1 contain excellent standards for documentation of cost-benefit studies.

I strongly believe in adequate documentation. To do this successfully requires a great deal of discipline during the study in terms of keeping adequate working papers and notes as you go. It is usually too late to begin good documentation when a study is nearly over and you are under pressure to write the final report.

VI. TOTAL PROGRAM COST ANALYSIS

Up to this point we have been discussing the analysis of individual competing systems and only briefly touched on total program costing when discussing incremental costs. I will now subdivide these two types of cost-benefit studies as follows (in ascending order of aggregation):**

*For an interesting set of questions suggested for a reviewer of a study to ask regarding costs, see I. Heymont, et al., [15].

**For a further discussion oriented to the DOD, see H. P. Hatry, [12].

<u>Study Type</u>	<u>Example</u>
<u>System</u>	
Intra-systems	Comparison of alternative configurations of System A
Inter-systems	Comparison of alternative systems A, B, C for high school dropout training
<u>Program</u>	
Major program	Comparison of alternative combinations of systems of the Job Placement Training Program
Total agency	Comparison of alternative combinations of major programs which comprise the total program of Health, Education and Welfare Department

I will only briefly discuss the two types of system studies, but go into more detail about the two types of Program Studies.

1. Inter-systems Analysis. To this point all our material was oriented to the comparison of alternative systems. We observed that costs and benefits are related in the analytical approach; we identified the salient features of estimating system costs, and the steps involved in preparing the estimates.

2. Intra-systems Analysis. The examination of alternative configurations of a single system is often referred to as trade-off analysis. The objective is to trade-off time, cost, and performance to find the optimum combinations under various assumptions. Except for the focus on alternative configurations of a single system, rather than competing systems, the estimating procedure is identical to that of inter-systems analysis. Applying intra-system analysis to our school sample we might examine the man-machine relationships within System A to find the optimum combination of teachers to computers and related equipment.*

3. Major Program Studies. The combination of systems into a Program or Major Mission Area is a significant feature of PPBS. The

* For detailed specifications and procedures regarding trade-off analysis for DOD systems, see AFSCM 375-5, [6].

analysis and selection of the systems which comprise the program may be viewed as a two-step procedure. In the first step individual systems are analyzed in order to gain an understanding of their capabilities, costs, and limitations. In the second step the more interesting candidate systems are analyzed in the context of the total program and its objectives. A total program is thus formulated.

The DOD Program I, Strategic Forces, is an example where program analysis has attained a rather sophisticated state. The offensive forces (our bombers and missiles) are balanced against our bomber and missile defensive forces plus a Civil Defense program to meet specified levels of Assured Destruction to our enemies and of Damage Limiting (to the U.S.). Decisions on individual strategic systems are difficult, if not impossible, to make outside this total program context. In our illustrative case, the systems we examined for training high school dropouts similarly must be further analyzed in a total program context before a final decision on them can be made. For example, a balance must be drawn between the type of training provided by Systems A, B, and C and other types of training programs.

4. Total Agency Studies. The development of a balanced grouping of major programs into a total for an agency is a most difficult task. It may not even be a meaningful task, as concerns the balancing of benefits, for agencies having a wide variety of objectives to accomplish. On the cost side, however, it is often very meaningful to prepare cost estimates of total agency programs. This is most useful, even required, for budgeting and programming purposes so that the total resource and dollar requirements of the agency can be determined. When costing military systems, we refer to this type of study as a Total Force Structure Study. A typical format for displaying total force structure costs (for the Air Force) is shown in Fig. 13.

Since major program and total agency study cost analysis techniques are too involved for detailed coverage here, I will mention only a few of their key features:

1. Emphasis on incremental costs (all operational systems are specified).
2. Emphasis on total program costs (all support elements are specified).
3. Emphasis on annual costs over a long time period.
4. Stress on a Base Case to measure incremental costs of alternative forces.
5. Presentation of forces, resources, and costs by program and program element.
6. Utilization of a computer model is essential for rapid, consistent costings.

(1) Emphasis is placed on incremental costs.* Recall that even when conducting a cost analysis of individual systems, we are always implicitly costing the systems in a total program or agency context. Assumptions are made regarding the inheritance from other systems of trained personnel, facilities, and equipment.

Total program cost analysis provides an explicit approach for incremental costing by establishing a framework within which all the resources available and the needs of all the systems can be considered simultaneously at successive intervals of time. This is done by specifying all of the systems which will be operational in the force and noting those resources freed by system phase-outs and those required by system phase-ins.

(2) Emphasis is placed on Total Program Costs. An explicit effort is made to specify and cost all program elements, and especially the support elements, which comprise a Total Program. Some of these elements will vary with the number and the activity level of the direct systems, while others will be relatively independent of them. For example, in attempting to specify a Job Placement Training Program, the administrative headquarters of the area Job Placement Training Director would be included. In costing a total agency, the Washington headquarters of HEW would be included. In sum, the objective is to specify all elements in a Total Program.

*For further discussion, see Novick, [18], pp. 60-63.

(3) Emphasis is placed on annual costs over a long time period. The time horizon is very important. Long-range planning is still the objective, and programs 5, 10, or 15 years ahead are involved. A key idea to note is that the systems must be projected several years beyond the desired analytical cutoff date in order to take into account long-lead-time items. If approved systems are not projected in this manner, then a characteristic tailing-off of costs will appear which may be misleading. This effect is shown in Fig. 14. The DOD Five-Year Defense Plan depicts military forces for 8 years and costs for 5 years. Of course some tailing-off always occurs as old systems phase out if new ones are not projected--but this knowledge is desirable in planning alternative defense programs. In fact, one of the values of the Five-Year Defense Plan is that it always depicts the spendout costs--that is, the costs of the military forces if no further changes were to be approved.

(4) Emphasis is placed on a Base Case for purposes of measuring the incremental costs of alternative forces. We are generally interested in looking at a number of alternative programs rather than just one, and in measuring the incremental cost of each alternative in relation to some base case. The base case is often the currently approved program, although it could be any postulated program from which variations are considered.

There is an important, though perhaps subtle, point to be made in connection with costing the approved program to serve as a base case. The point is that, in DOD, for example, the approved program is already costed in the Five-Year Defense Plan. However, this costing was done for a different purpose--that of programming. Therefore, alternatives costed by other methods, such as those used in planning studies, cannot be directly compared with the Five-Year Defense Plan Costs. The observation is not intended to be critical. Rather, I merely wish to point out the nature of the process, wherein literally hundreds of staff personnel are involved in costing the Five-Year Defense Plan. Currently, judgment rather than consistent ERs is used in estimating. Estimates are

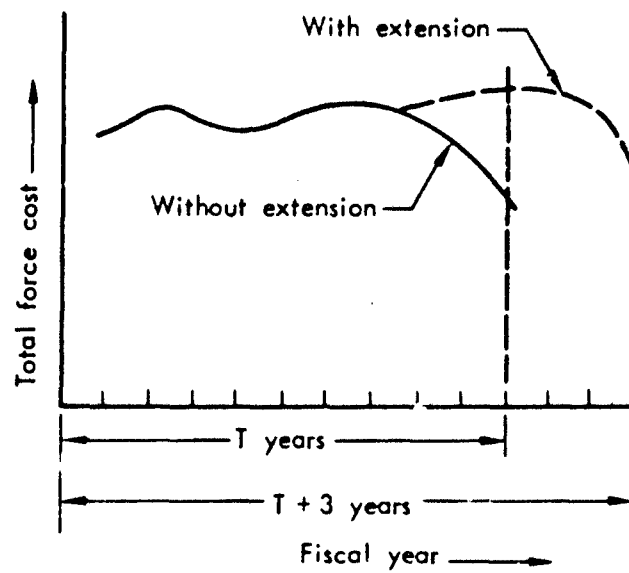


Fig.14—Extending the period of analysis
Source: Novick, [18], p.66

tampered by administrative budgetary ceilings (these ceilings are even projected for several years ahead); in general, the results are just not reproducible in the scientific sense of the word.

To obtain reasonable estimates of the incremental costs for alternative programs it is mandatory that the systems in the approved program be costed by a methodology consistent with that used to cost the alternatives. This base case can then be used to measure differences from the approved program. It can then be assumed that the differences are additive to the approved Five-Year Plan costs.

(5) Forces, Resources, and Costs are displayed by Program and Program Element. As previously noted, a typical display, (for the Air Force) is shown in Fig. 13.

(6) Use of a computer model is essential for rapid, consistent costings.* A computerized model is essential for timely analysis of programs on any suitable basis. By computerized model I mean more than just a set of computer program instructions--I refer also to a trained analytical staff who develop and supply appropriate factors to the computer program. The objective is to cost the alternative forces both rapidly and consistently in order that comparisons can be made to determine incremental costs.

Time-phasing. The final topic to be covered is the time-phasing of cost estimates. Time-phasing (the annual incidence of costs) is essential for program costing, for individual system costing where discounting to a present value is to be done, and for many other individual system costings for the reasons listed below:

First, the impact by fiscal year by funding category is important because of possible budgetary ceilings either on total agency budgets or on pockets of funds, such as military construction. Two particular measures of financial impact of interest are those of Total Obligational

* For further descriptions of some models and related analytical activity, see Novick [18], Chap. III; Grosse [19], and String [20].

Authority (TOA) and Expenditures. TOA consists of new obligational authority (the authority to incur obligations to pay) asked of Congress plus obligational authority carried over from prior years which is available for funding new programs, plus reimbursements for certain items. The DOD Five-year Program is displayed in TOA terms. The TOA totals are converted into Expenditures, payments of money from the Treasury. Both measures are important, TOA to predict requests for funds to Congress and Expenditures to predict the impact of the national cash flow.

Figure 15 depicts a timing relationship between TOA and Expenditures.

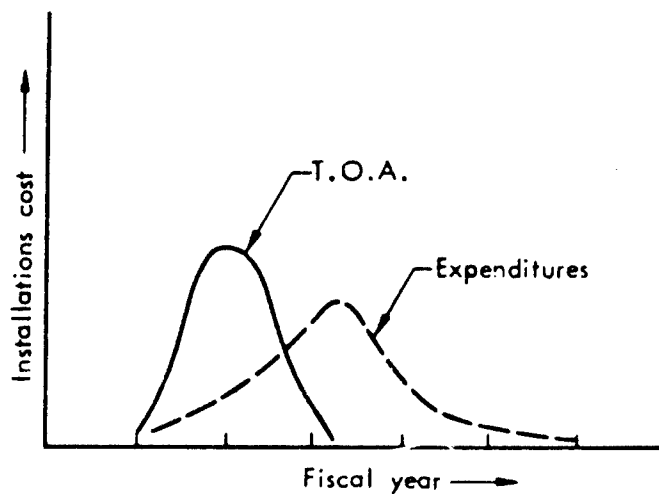


Fig.15—Timing of T.O.A. and expenditures

Source: Novick, [18], p. 66

Second, time-phasing provides a better visibility into the matter of inheritable assets, which, as we have noted before, is an essential component in the calculation of the incremental cost of a system. Being explicit about the time-phasing helps to improve the estimates of inheritable assets, although this technique alone is not as important as that of explicitly costing the total program, thus taking into account all systems which could provide inheritable assets. Figure 16 compares time-phased costs with the system cost categories.

Third, it shows in annual increments what is needed to phase from the current program to a recommended program and brings to light the producibility, financial, personnel, etc., aspects of the plan.

Methods for time-phasing estimates depend on the problem at hand and on the available information.* One technique for making rough estimates of systems in a conceptual stage is called the Percentage-Time Percentage-Cost (PTPC) technique. Figure 17 illustrates the technique. It shows the dollar costs (right-hand scale) and the estimated actual time corresponding to the percentages (left-hand scale). The conventional technique for estimating the time phasing of costs for those systems having more information available involves the development of time-phased production schedules, such as that shown in Fig. 18, for each resource and the application of appropriate funding lead or lag times. For example, aircraft production may require a 24-month lead time to estimate MOA pertaining to the first production lot, and, say, an 18-month lead time thereafter.

I wish to close this topic with a note of caution. The time-phasing of a total estimate generates many seemingly precise numbers. Do not confuse this precision with accuracy! The uncertainty surrounding the original estimate is not changed by presenting it as a series of annual estimates.

* See AFSC 173-1 [11], pp. 7-4 to 7-13.

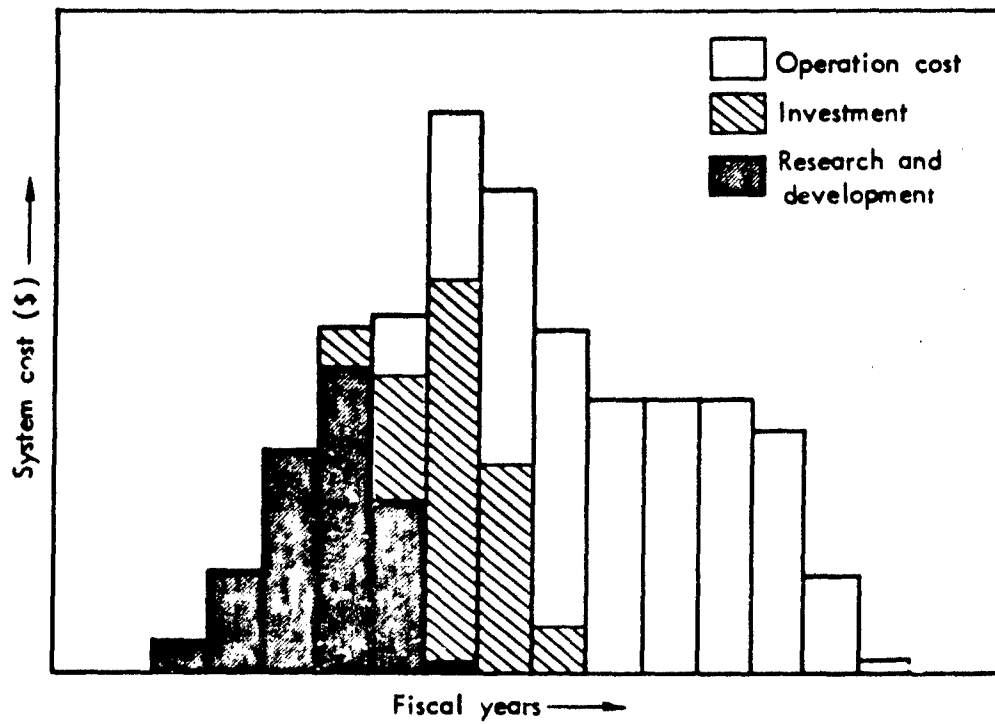


Fig.16—System costs time-phasing (by fiscal years)

Source: Large [10], p. III-11

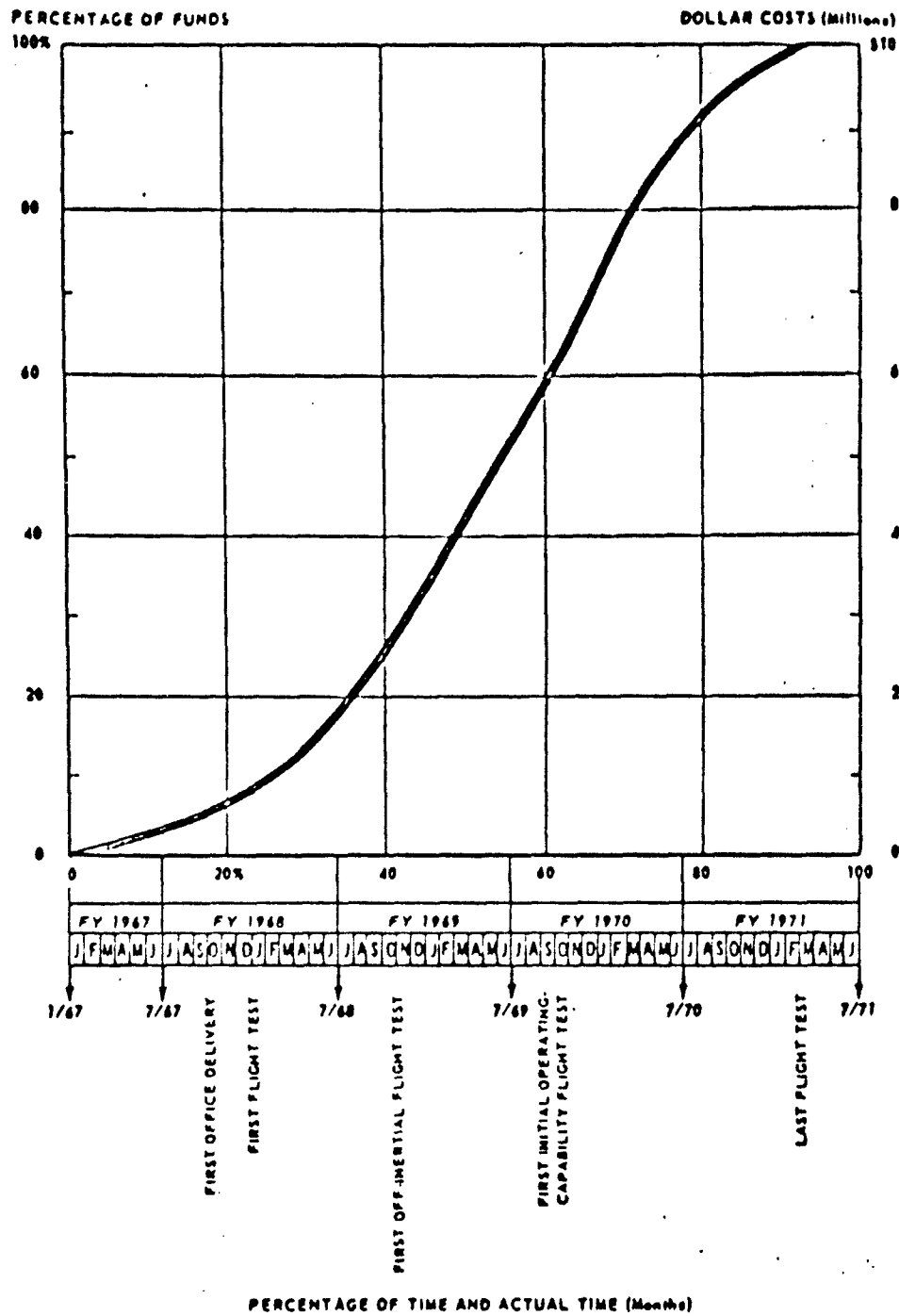


Figure 17—Example of the RTPC technique

Source: AFSC 173-1, [11], p.7-6.

Figure 18—Production schedule for an aircraft system

Source: AF5CL 173-1, [11], p. 7-9.

CONCLUDING REMARKS

In this discussion, I have attempted to review the concepts, principles, and the general approach of systems cost analysis in support of cost-benefit studies. The role of costs was considered both in individual system analysis and within the broader context of program analysis. This description of resource analysis was intended primarily for the users of cost estimates, as opposed to cost analysts. Users of cost estimates must face the critical task of judging cost estimates and evaluating their suitability and quality. The intent of this discussion was to improve the ability of those involved in the conduct of cost-benefit studies in non-defense agencies to appreciate the role of costing, to understand the limitations of cost analysis, and to establish adequate guidelines for the costing work done in support of these studies.

Appendix

COSTING GUIDELINES
FOR
DEPARTMENT OF DEFENSE COST-EFFECTIVENESS STUDIES

May 1, 1966

Office of the Assistant Secretary of Defense (SA)
Resource Analysis

INTRODUCTION

Cost estimates have become an integral part of the submission of weapon systems studies and proposals within the Department of Defense. These estimated costs are scrutinized at each stage of review of the study or proposal. In an effort to establish a standard for preparing and presenting such estimates, and to achieve greater consistency and comparability among cost studies, these guidelines have been published.

A set of general costing guidelines is presented to assist study teams in fulfilling cost requirements. Additional ad hoc ground rules, based on the unique characteristics of a particular study, will normally also be required. Military departments are encouraged to prepare such ground rules on their own internal studies. Costing for studies being prepared for OSD should normally be compatible with the guidelines contained herein.

This set of guidelines is a modification of a version prepared for inclusion in the "Department of Defense Guide for Contract Definition," currently in preparation. These guidelines are, therefore, written to apply to a wide range of cost-effectiveness studies.

COSTING GUIDELINES FOR DOD COST-EFFECTIVENESS STUDIES

It is difficult to prescribe very specific costing rules which apply across the board to all Department of Defense cost-effectiveness studies. Each study will have its own objectives, problems, and emphasis. The following costing guidance, therefore, is necessarily somewhat general.

The Military Departments during the initial stages of a study, using these guidelines as a starting point, should prepare as appropriate a more specific set of costing guidelines based upon the specific objectives of the study at hand.

Should specific questions arise concerning study costing practices, the OASD(SA), Resource Analysis Office, is available to the Military Departments for consultation. Military Department contractors should direct their questions to the Military Department's Project Manager.

It is to be noted that the Costing Guidelines and discussion in this paper are not for the purpose of providing guidance for the preparation of contractor hardware proposal estimates. Contractor hardware proposal estimates will typically require considerably more detail; such estimates, however, should be compatible with the costs used by the contractor in his cost-effectiveness studies.

1. All significant costs that might affect the choice of alternatives should be included in the analysis. All phases of the life cycle of a system should be considered for inclusion--development, investment, and operating costs. Normally, studies will need to include costs for all three phases to make certain that the complete costs impacts are presented.

Emphasis should be placed on identification of those costs which differ among the various alternatives being considered. Costs which are expected to be the same for all alternatives considered in the study, (such as Service headquarters' staffs or certain base operating costs), even though these costs are required during the time period examined in the study, may be excluded. (However, there may be instances where it is desirable to consider total costs, including these other costs.) Where more than one Military Department or contractor is undertaking a study, the danger arises that one and not the other may exclude certain costs. Where such possibilities can be anticipated, the Military Departments should provide advanced guidelines which resolve this problem. The results of the studies would otherwise not be truly comparable until adjustments were made for the differences.

2. Indirect and supporting costs (such as base operating support, combat support units, tanker support for an aircraft force, supply ship or tender support for a force of ships, special training or testing requirements, etc.) should be considered a part of the total system cost and should be included, as appropriate to the study.

3. "Sunk" costs (i.e., costs which can reasonably be assumed to have been expended prior to the beginning of the time period examined in the study) are not relevant and should be excluded. (However, on occasion the display of certain sunk costs may be desirable for reference purposes, e.g., to specify which costs have been excluded from the study.)

4. In order to permit proper evaluation and understanding of the work, each study should be fully documented as to the source, techniques, cost-estimating relationships and assumptions used to develop the costs. This is especially important for the new systems which are being evaluated and are not currently included in the Department of Defense approved Five-Year Force Structure and Financial plan. Where different contractors are performing parallel CDP studies, it is also necessary to be able to identify any major differences in costing assumptions among the contractors. Preferably, an individual cost "factor" sheet should be provided on each system considered in the analysis. The sheet would summarize the cost and planning factors utilized in the study in such a manner that an outside analyst could reconstruct the summary costs presented in the study. An example of such a format is provided in Exhibit 1. It should be noted that the cost backup should be presented on a "per force unit" or "per force unit-year" basis to facilitate review of the cost details. Where a force unit consists of major procurement items or other cost elements for which cost-quantity (learning) curves are used in cost estimation, the individual curves should be provided. Since the "unit" cost will then vary with the total quantity, "per force unit" costs need not be provided for such cost elements. Where Military Department cost models, program factors, or other widely distributed compilations of cost data, are used to estimate costs, a simple reference to those publications is sufficient. For significantly new or sophisticated systems, and those not currently included in the DOD approved list, adequate cost-supporting data should be included. The major cost-determining characteristics of the system as noted in (5) below should be included in the study submission.

5. Each alternative system and major hardware item should be clearly described as to its major cost generating characteristics used in the study. For example, the following characteristics should be identified where pertinent to the derivation of the cost estimates.

- Hardware operational performance characteristics such as accuracy, speed, and resolution.
- Major design characteristics, such as weights, size, and specific impulse.
- System operating concepts such as aircraft/missile base dispersion assumptions, tanker-to-bomber ratios, tender-to-SSBN ratios, number of missiles carried per aircraft, number of maneuver battalions per division base, etc.

4. In addition, "planning" factors such as the following, where used to derive the total cost figures, should be identified:

- Activity levels such as the flying hours per aircraft per year.
- "UE," shipfill, or basic load quantity per force unit.
- Annual test or training consumption factors.
- Aircraft attrition rates.
- Pipeline and spares factors.

6. Costs for cost-effectiveness studies normally should be stated in constant dollars of the latest year available. That is, projected price level changes should be excluded. This is a standard practice which has the advantage of avoiding the necessity for predicting price level changes and, if not otherwise required, avoids the necessity for time phasing the costs by year (which is required when applying projected price level indices). However, special occasions may arise when it may be necessary or preferable to include projected price level changes in certain of the estimates. In such cases, the price change assumptions should be clearly stated and the magnitude of such changes indicated.

7. In order to achieve consistency and comparability among DOD cost studies, the cost element categories and data used in the study should be, as far as possible, compatible with the latest information from official Military Department sources. At present, the suggested sources are: Air Force Cost Division (AFABF), Army Cost Analysis Directorate (Army Comptroller), and Navy - Program Appraisal Division (CNC-OP90). The data available from these sources are not likely, however, to be completely satisfactory where detail at the subsystem level is required. However, use of the latest official Military Department cost and planning factors manuals, available through these offices, to the extent that they are applicable, will save considerable time, effort, and the need for substantiation. It is not intended, however, to restrict study teams to these factors. It is recognized that a study team may not be able to use this data or may disagree with, or at least prefer to use, information at variance with these sources. This is permissible, but the reasons should be provided.

8. The exact quantity of any proposed hardware that would eventually be procured can seldom be completely resolved at the time of the cost-effectiveness study. It is, therefore, desirable that the cost information supplied permit estimation of costs at various quantities within a reasonable range of possibility, as excursions from the cases directly examined in the study. Procurement cost versus quantity relationships (expressed, for example, as equations or cost-quantity curves) should, therefore, normally be provided. These should be provided for each major procurement item. This might mean a complete system such as a complete aircraft or missile, or where appropriate to the study, a subsystem such as a particular avionics package, the propulsion system, airframe, etc. In addition, the effect of quantity, if any, upon development and annual operating costs should be indicated. These relationships should, to the extent possible, take proper cognizance of the recurring versus non-recurring costs. That is, recurring costs

(such as recurring tooling for aircraft airframes) should be distinguished from the non-recurring costs (such as airframe initial tooling). If the rate of production (as well as the total production quantity) is also a significant cost influencing variable for the major procurement items, the appropriate cost implications of major production rate changes should be indicated.

9. The level of detail to which systems should be broken down and for which costs are to be displayed depends upon the nature and depth of the individual study. The originator of the study should specify in advance the level of detail needed. More detail will normally be required for CDP than for earlier stage "Concept Formulation" studies.

10. The major uncertainties in the cost estimates should be identified. To the extent possible, these uncertainties should be quantified (even if only subjectively) as to the magnitude and the likelihood of the uncertainty. This might be done, for example, by providing estimates of the range and "most likely" values or by providing an estimated "probability distribution" on the cost estimates for each major alternative. For major cost uncertainties, the sensitivity of the study results to these uncertainties should be indicated; in other words, "sensitivity analysis" should be performed whenever feasible. Major cost uncertainties may be caused by assumptions pertaining to system characteristics (such as those listed in (5) above) as well as to specific cost factors.

11. A number of possible cost measures have been suggested at one time or other for cost-effectiveness studies. The major ones of interest are:

a. The sum of development plus investment plus some specified number of years (commonly from five to ten) of level-off annual operating costs. Operating costs incurred during periods of buildup or phase-down are ignored.

b. Annual costs over some specified period. That is, the costs for each alternative are time phased thereby permitting examination of each year's funding requirements.

c. Cumulative actual costs over some specified number of years.

In addition, on occasion, analysts have further modified each of these cost measures by one or both of the following adjustments:

a. Application of "discount" rates to the estimated costs for each year. The discount rate attempts to consider the time value of money. It is similar to an interest rate in indicating that current dollars, because of their ability to earn compounded interest dollars, are more valuable now than dollars which are available later in the future. The annual discounted costs for each alternative can be summed to give a "present worth" of the costs of each alternative.

b. Adjustment of the costs for an estimated "residual value" of each alternative. Where systems being compared have significantly different expected lifetimes, consideration in the study of a relatively short time period may not otherwise consider the potential investment savings possible in a subsequent time period from having procured the longer lived systems. The residual value adjustment (analogous to "scrap values" in equipment replacement studies) attempts to represent the economic value of any life expectancy remaining at the end of the period of the study.

It is difficult to pre-specify exactly which cost measure should be used in a study. However, the following general statements reflect the present thinking.

a. In all cases, figures which reflect the estimates of full costs, without such adjustments as discounting and residual values, should be provided in the study.

b. Studies may also display these costs discounted and/or adjusted for residual value if the analysts believe this is appropriate to the situation. If residual values are utilized, such values should be identified. A display of the sensitivity of the study conclusions to these considerations is appropriate. Where preliminary indications suggest that similar funding patterns and similar system lifetimes are involved among the systems being compared, it is preferable to avoid the additional effort and possible confusion required in making the discounting and/or residual value analyses. Where discounting or residual value adjustments are used, the study should document the major assumptions, such as those concerning the choice of discount rates, the selection of the system lifetime, and the particular procedure used to determine the residual values.

c. Studies intended for immediate use in making major force decisions, particularly where specific force levels and phasings are involved should, in general, emphasize the more realistic cost measures, annual and cumulative costs, as distinguished from the aggregative cost measures using some number of years of level-off operating cost. When used for specific, time-phased, force recommendations, this will permit the study to provide a more accurate reading of the actual funding implications. Realistic considerations such as the phasing-in periods and phasing-out periods will then be incorporated, and costs and effectiveness time patterns can be examined for undesirable peaks or dips. Both the annual costs and the cumulative costs through selected time periods should be shown.

d. For those studies which emphasize comparisons (without aiming at specific time-phased force level recommendations) involving systems or designs with approximately the same life cycles, the cost measures using the sum of development, investment, and some specified number of years of level-off operating costs should be used. Many CDP studies and Concept Formulation studies will probably fall into this

category. The costs obtained are not as realistic but would provide sufficient information for the more limited study objectives of making "snapshot" comparisons among alternative systems or among alternative designs of a specific system. Thus, this measure should be most useful for studies emphasizing the screening of candidates with the same time phasing, while the time-phased cost measures should be used in studies which compare alternative force levels and phasings utilizing the major candidate systems which survived the screening studies.

e. Where discounting is applied, the discount rate should reflect only the time value of money. It should, in general, not include an allowance for "uncertainty." As described in (10), the problem of cost uncertainty should preferably be expressed explicitly and not "lumped" into a rate such as used in discounting. No official DOD discount rate has been established. Rates between 5 and 10 percent should normally be used. Rates used outside this region should be explained.

f. When time-phased costs are shown, these costs should, in general, represent Total Obligational Authority (TOA) for each fiscal year rather than Expenditures. They should be on a fiscal year rather than on a calendar year basis.

12. Some systems considered in a study may have applicability to other missions or other uses which are not directly considered in the study. No completely satisfactory procedure for handling these situations is currently known. In general, however, cost deductions should not be made to those systems which do have such spillover effects. In any case, a discussion of any side benefits accruing to each of the candidate systems should be clearly indicated and would have to be considered when making study conclusions.

13. The major problem in cost analyses, of course, is that of preparing the basic cost estimates. Some general principles can be stated:

a. A first step is to establish, and carefully define, a set of "cost categories" for each type of system being costed, as for example: fuel cost, maintenance cost, airframe production, etc. This set of cost categories should include all significant costs without duplication. As indicated earlier, it is desirable that these cost categories be compatible with the official Military Department categories. The format in Exhibit 1 illustrates such a set of categories which recently was used in a major force structure analysis. However, more detail, particularly in CDP studies, may be desirable for particular studies. Each cost category should be such as to permit its costs to be distinguished from that of any other cost category.

b. Where considerable cost uncertainty exists, emphasis should be placed upon the consistency of assumptions among the alternatives being compared. Though the absolute value for each alternative may be in considerable doubt, at times more confidence may be had in the relative costs, thereby providing useful comparative information.

c. In making estimates of costs for systems currently in the inventory, data on recent actual costs will normally be the best source of data for making projections into the future (modified, of course, for anticipated changes).

d. In making estimates of costs for future systems, those not in the inventory and perhaps only in the most preliminary design stages, other procedures are necessary. "Engineering estimates," those based primarily upon examination of the components of the specific system proposed, is the most common method applied. Another technique is strongly recommended to be used with (and, in situations where engineering estimates are not feasible, replace) the engineering estimates. This is to develop estimating relationships based upon historical data on other programs, which relate individual elements of cost to selected physical and performance characteristics of the item. Statistical regression analysis has been usually utilized in this process.

Where statistical cost-estimating relations are used in a study and they are obtained from available, documented sources, reference to those sources along with necessary commentary as to the specific application will normally be sufficient documentation.

Exhibit 1

ILLUSTRATIVE FORMAT OF COST FACTOR SHEET*
HYPOTHETICAL AIR FORCE AIRCRAFT SYSTEM

<u>I. COST CATEGORIES</u>	<u>FACTOR/COST</u>	<u>BASIS OF ESTIMATE</u>
<u>I. R&D</u>		
Airframe	\$110M	Statistical cost-estimating relation; see Note 1**
Engines	\$ 35M	Modified contractor A estimate; see Note 2**
Avionics	\$ 20M	Modified Contractor B estimate; see Note 3**
Total	\$165M	(These notes on R&D should indicate the specific years and costs for each year.)**
<u>II. INVESTMENT</u>		
<u>Related to Flyaway Cost</u>		
Aircraft flyaway	Cost-quantity curves for airframe, engines, and avionics costs should be attached. (An example is shown in Exhibit 2.)	15 UE aircraft/squadron + 2 command support acft/sq + attrition acft. (See Note 4** for method of computing attrition acft.) (See Note 5** for presentation and explanation of cost-estimating relations used to derive the flyaway cost curves.)
Initial spares	22% of acft flyaway	Modified AF factor; see Note 6**
Peculiar AGE	2% of acft flyaway	Modified AF factor; see Note 7**
Technical data	1 1/2% of acft flyaway	Modified AF factor; see Note 8**
<u>Related to No. of Sq</u>		
Military construction	\$5M per dispersal site	Estimate; see Note 9**
Common AGE	\$1M per squadron	AF factor; see Note 10**
Initial personnel training	\$9M per squadron	250 Officers @ \$8400 per sq. 1800 Airmen @ 3600 per sq. See Note 11**

Exhibit 1 (Cont.)

<u>COST CATEGORIES</u>	<u>FACTOR/COST</u>	<u>BASIS OF ESTIMATE</u>
III. RECURRING		
<u>Related to Flyaway Cost</u>		
Modifications + common ACE	2.5% cum avg flyaway	See Note 12**
Related to No. Sq POL	\$1.1M/squad/yr	\$210 per flying hour; 360 F.H./UE acft/yr; see Note 13**
Depot maintenance	\$1.4M/squad/yr	\$250 per flying hour; 360 F.H./UE acft/yr; see Note 14**
Replenishment spares	\$1.3M/squad/yr	\$240 per flying hour; 360 F.H./UE acft/yr; see Note 15**
Pay & allowances--officers	\$2.9M/squad/yr	250 officers/squad @ \$11,400/yr; see Note 16**
Pay & allowances--airmen	\$7.9M/squad/yr	1800 airmen/squad @ \$4400/yr; see Note 17**
Pay--civilians	\$0.3M/squad/yr	40 civilians/squad @ \$7100/yr; see Note 18**
Other support	\$2.7M/squad/yr	\$1300/military; see Note 19**
Replacement training	\$2.3M/squad/yr	25% turnover rate (see "initial training"); see Note 11**
Total	<u>\$19.9M/squad/yr</u>	

IV. OTHER

Missiles: A separate Cost Factor sheet should be provided to display the costs and to indicate the method for computing the number of missiles required per aircraft squadron.

Tankers: A separate Cost Factor sheet should be provided to display the tanker cost factors and to indicate the number of tankers required per aircraft squadron

* This is purely an illustration to give an idea as to the type of information desired. Both the list of cost categories and the specific factors and costs used should be established to meet the needs of each individual study. CDP studies, for example, may require considerably more subsystem detail.

** Notes 1-19 should further describe the basis for the factors or costs including the sources from which obtained.

REFERENCES

1. Novick, David (ed.), Program Budgeting: Program Analysis and the Federal Budget, Harvard University Press, Cambridge, Mass., 1965.
2. Prest, A. R., and R. Turvey, "Cost-Benefit Analysis: A Survey," The Economic Journal, Vol. LXXV, No. 300, December 1965.
3. McKean, R. N., Efficiency in Government Through Systems Analysis, John Wiley & Sons, Inc., New York, 1958.
4. Quade, E. S. (ed.), Analysis for Military Decisions, The RAND Corporation, R-387-PR, November 1964.
5. Bureau of Budget Circular 66-3, Planning-Programming-Budgeting, October 1965.
6. Air Force Systems Command, Systems Engineering Management Procedures, AFSCM 375-5, March 1966.
7. Hitch, C. J., and R. N. McKean, The Economics of Defense in the Nuclear Age, Harvard University Press, Cambridge, Mass., 1960.
8. Jones, M. V., System Cost Analysis: A Management Tool for Decision-making, The MITRE Corporation, TM-4063, July 1964.
9. Slivinski, S. C., The RAND Cost Analysis Department Data Bank, The RAND Corporation, P-2985, September 1964.
10. Large, J. P. (ed.), Concepts and Procedures of Cost Analysis, The RAND Corporation, RM-3589-PR, June 1963.
11. Air Force Systems Command, Cost Estimating Procedures, AFSCM 173-1 October 1965.
12. Hatry, H. P., The Use of Cost Estimates in Cost-Effectiveness Analysis, Office of Assistant Secretary of Defense (Comptroller) Programming Office, June 1965.
13. Asher, Harold, Cost-Quantity Relationships in the Airframe Industry, The RAND Corporation, R-291, July 1956.
14. Brewer, G.M., The Learning Curve in the Airframe Industry, Thesis, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, SLSR-18-65, August 1965.
15. Heymont, I., et al., Guide for Reviewers of Studies Containing Cost-Effectiveness Analysis, Economics and Costing Department Study 63.2, Research Analysis Corporation, October 1965.
16. Weapon System Effectiveness Industry Advisory Committee (WSEIAC), Final Report, Headquarters AFSC TR-65-6, Andrews Air Force Base, Maryland, January 1965.
17. Fisher, G. H., Total Force Structure Cost Analysis, The RAND Corporation, RM-3070, April 1962.
18. Novick, David, System and Total Force Cost Analysis, The RAND Corporation, RM-2695, April 1961.

19. Grosse, R. N., Army Cost Model, The RAND Corporation, RM-3446-ASDC, December 1962.
20. String, J., A Model for Projecting Costs of Space Exploration, The RAND Corporation, P-3119, April 1965.